SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Sludge Concentration Process—Laboon

New York's Owls Head Plant—Steffensen

Lethal Properties of Ultrasound—Horton, et al.

Specialty Paper Mill Wastes—Rudolfs and Nemerow

Chemical and Antibiotic Wastes—Vogler, et al.

APRIL, 1952—VOL. 24, No. 4

Make Plans to Attend

SILVER ANNIVERSARY MEETING

OF THE

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

NEW YORK SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

HOTEL STATLER
NEW YORK CITY

October 6-9, 1952

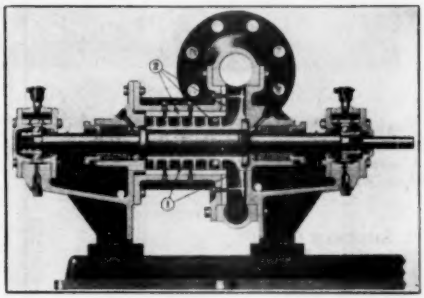
FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS
325 ILLINOIS BUILDING CHAMPAIGN, ILLINOIS

Chicago Pumps for Sewage and Sludge

SCRU-PELLER SLUDGE PUMPS

The Scru-Peller Pump was specifically designed to handle sludge. Coarse stringy material is cut and cannot wrap or bind the impellers.

1. **SCREW and IMPELLER** are keyed on the shaft and held firmly against a shoulder on the shaft by a nut. The screw has two flights; and the impeller has two blades. Each flight in the conveyor connects directly with its own blade of the impeller.
2. **CUTTING EDGES.** There are four stellited cutting bars and a shear ring in the screw housing. There are four more cutting bars in the pump casing. The stellited edges of the screw and the edges of the impeller blades act against the cutting bars and shear ring, completely chopping all coarse solid material into small pieces that cannot clog or slow the pump.



FLUSH-KLEEN EJECTORS

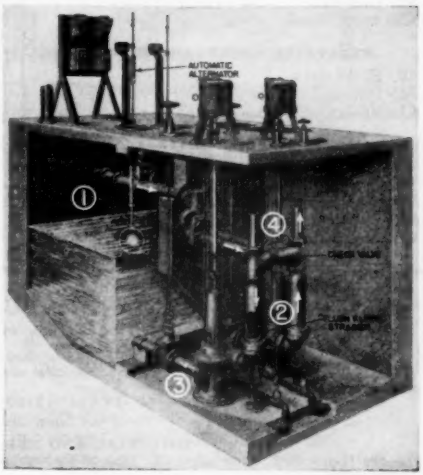
FLUSH KLEEN pumps provide automatic, trouble-free service in sewage lift-stations. They require no manual attention except periodic lubrication and inspection. No labor is required for disassembling and cleaning clogged pumps. FLUSH KLEENS are absolutely clog proof. The impellers handle nothing but strained sewage, minimizing wear and maintaining pump balance. They are the only absolutely clog proof sewage pump. The FLUSH KLEEN will pump anything that will pass through the pipe regardless of type or quantity of material.

FILLING WET WELL

1. Sewage flows through inlet pipe.
2. Coarse matter is retained on strainer.
3. Strained sewage flows through idle pump to wet well.

PUMPING

3. Strained sewage is pumped from wet well.
2. Coarse matter is backwashed from strainer.
4. Special check valve closes; sewage and coarse matter are pumped to sewers.



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CHICAGO PUMP COMPANY
SEWAGE EQUIPMENT DIVISION
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Flush Kleen, Scru-Peller, Plunger Horizontal and Vertical Non-Clog Water Seal Pumping Units, Samplers.

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SEWAGE AND INDUSTRIAL WASTES

REG. U. S. PAT. OFF.

A monthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works.

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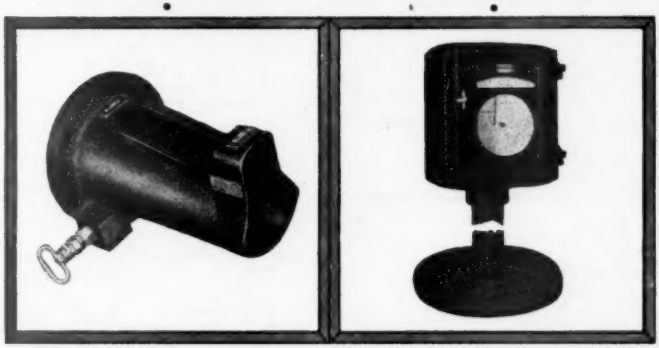
FOR **MATCHLESS** PERFORMANCE



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FOR OPEN FLOW

Builders Kennison Nozzle provides high-accuracy metering of partially filled pipes or open channels. Extremely efficient from low to high rates of flow, this nozzle has a self-scouring action which prevents clogging by debris. Factory-built metering element eliminates costly and "tricky" field construction — greatly simplifies installation and assures accurate performance.

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FOR OPEN FLOW

Builders Flo-Watch Instrument, with weatherproof case, is the perfect partner for the Kennison Nozzle. Completely protected against weather or tampering, this instrument gives you totalizing, indicating, and recording of flow right at the nozzle. Where economy of installation is important, you can't beat this meter. Builders also offers Chronoflo Telemeters and Pneumatic Systems for transmitting flow information to central control points.

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to measure SEWAGE, SLUDGE or TRADE Wastes?

Simplex Type H Venturi Meter

When used with the proper kind of Venturi Tube, the Type H Meter measures sewage, sludge, and trade wastes as accurately as clear liquids.

This type of meter is designed to operate under two maximum differential pressure heads. The first, 114.4" of water, permits measurement over a 13 to 1 range while the second, 64.5" of water, provides for a 10 to 1 measuring range. Standard meter design includes indicating, recording and totalizing mechanisms.

Versatility of installation and adaptability to varying flow rates make the Type H Venturi Meter ideal for accurate, long-range measurement. *Write for Bulletin No. 401 to Simplex Valve & Meter Company, Dept. 4, 6719 Upland Street, Phila. 42, Pa.*

SIMPLEX

VALVE AND METER COMPANY

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Association	*Place*	*Time*
Maryland-Delaware Water and Sewerage Association	Wardman Park Hotel, Washington, D. C.	April 17–18, 1952
California Sewage Works Association	Casa Del Rey Hotel, Santa Cruz, Calif.	April 23–26, 1952
Virginia Industrial Wastes and Sewage Works Association	Hotel Roanoke, Roanoke, Va.	May 12–13, 1952
Michigan Sewage and Industrial Wastes Association	Park Place Hotel, Traverse City, Mich.	May 19–21, 1952
Ohio Sewage and Industrial Wastes Treatment Conference	Commodore-Perry Hotel, Toledo, Ohio	May 21–23, 1952
New England Sewage and Industrial Wastes Association	Hotel Elton, Waterbury, Conn.	May 22–23, 1952
Alabama Water and Sewage Assoc.	Pitts Hotel, Auburn, Ala.	June 4–6, 1952
Central States Sewage and Ind. Wastes Assn.	Loraine Hotel, Madison, Wisc.	June 25–27, 1952
Pennsylvania Sewage and Ind. Wastes Association	Pennsylvania State College, State College, Pa.	Aug. 27–29, 1952
Iowa Sewage Works Association	Grinnell College, Grinnell, Iowa	Sept. 9–11, 1952
Rocky Mt. Sewage Works Assn.	Frontier Hotel, Cheyenne, Wyo.	Sept. 15, 1952
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Andrew Johnson Hotel, Knoxville, Tenn.	Sept. 15–17, 1952
South Dakota Water and Sewage Works Conference	Marvin-Hughitt Hotel, Huron, So. Dakota	Sept. 17–19, 1952
Mo. Water and Sewerage Conference	Governor Hotel, Jefferson City, Mo.	Sept. 21–23, 1952

SILVER ANNIVERSARY MEETING

Federation of Sewage and Industrial Wastes Associations

in conjunction with

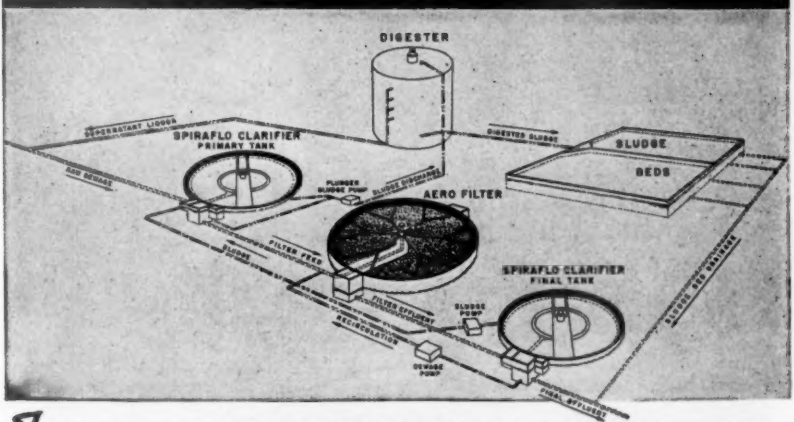
New York Sewage and Industrial Wastes Association

Hotel Statler, New York City

October 6–9, 1952

Pacific Northwest Sewage and Industrial Wastes Assn.	Multnomah Hotel, Portland, Ore.	Oct. 23–24, 1952
The Canadian Institute on Sewage and Sanitation	Seigniory Club, Montebello, Que.	Nov. 3–5, 1952
North Carolina Sewage and Industrial Wastes Assn.	Skyland Hotel, Hendersonville, N. C.	Nov. 10–12, 1952
Florida Sewage and Industrial Wastes Association	San Carlos Hotel, Pensacola, Fla.	Nov. 16–19, 1952

There's a YEOMANS Plant
FOR EVERY WASTE TREATMENT NEED!



THIS LOW RATE, HIGH CAPACITY TRICKLING FILTER PLANT IS ESTABLISHING AMAZING RECORDS FOR HIGH PURIFICATION AT EXCEPTIONALLY LOW COST

These figures show a typical result produced by a Yeomans installation of the "Aero-Filter" and "Spiraflo" Clarifier in combination.

Overall plant efficiency is always higher when these units are used together. The method is especially effective for treating strong industrial wastes.

OPERATIONAL DATA . . . SPIRAFLO—AERO-FILTER PLANT *

1949 Date	Sewage Flow M.G.D.	Raw Sewage		Primary Effluent				Final Effluent				Overall Plant Reduction	
		Sus. Solids PPM	B.O.D. PPM	Sus. Solids PPM	Per Cent Reduction	B.O.D. PPM	Per Cent Reduction	Sus. Solids PPM	Per Cent Reduction	B.O.D. PPM	Per Cent Reduction	Sus. Solids Per Cent	B.O.D. Per Cent
6-15	0.2996	210	255	79	62.4	136	46.6	28	64.6	18	86.8	86.6	93.0
6-16	0.2467	425	260	85	80.0	127	51.2	23	73.0	19	85.1	94.6	92.6
6-17	0.2554	410	235	124	69.7	141	40.0	28	77.4	18	87.3	93.3	92.4
6-18	0.2487	308	222	76	75.4	108	51.4	34	55.3	16	85.2	89.0	92.8
6-19	0.1753	222	218	64	71.2	132	39.5	17	73.5	—	—	92.4	—
6-20	0.2666	262	320	88	66.4	147	54.1	20	77.3	30	79.6	92.4	90.6
6-21	0.2279	240	215	78	67.5	138	35.8	19	75.7	20	85.7	92.0	90.7
Average	0.2456	297	247	85	70.5	132	45.5	24	71.0	20	85.0	91.5	92.0

* Name of plant furnished on request, as well as operating data from other installations.

"Spiraflo" Advantages

- Increased B.O.D. and settleable solids removal —influent is introduced tangentially into annular race around the periphery. Sewage spirals downward slowly and enters main clarification compartment at the bottom of the tank. Uniform, slow diffusion of waste under the skirt results in greatly reduced velocities and provides maximum removal of settleable solids.
- Greater removal of finely divided particles—due to upward flow through sludge blanket. This increases flocculation and results in more effective removal of finely divided particles before waste enters the effluent weirs.
- Straight-wall design minimizes construction costs.

"Aero-Filter" Advantages

- Thorough uniform distribution—therefore costly recirculation for dilution is unnecessary
- Operating cost is lowest of any type of complete sewage treatment
- Uninterrupted and almost complete momentary bed coverage minimizes troubles from odors, freezing, ponding, filter flies
- All returns made direct to the filter—no oversize primary tank required.

FOR INDUSTRIAL WASTES, TOO . . . Many types of industrial wastes can be successfully treated by direct application to the Aero-Filter without preliminary sedimentation.

Bulletins containing full details and helpful engineering data will be sent promptly upon request

YEOMANS

A COMPLETE LINE OF SEWAGE AND WASTE TREATMENT EQUIPMENT AND PUMPS FOR BUILDINGS, MUNICIPALITIES, INDUSTRIAL APPLICATIONS

YEOMANS BROTHERS COMPANY
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Please send these bulletins:

- ☐ "Aero-Filter"—No. 6570
- ☐ "Spiraflo" Clarifier—No. 6790

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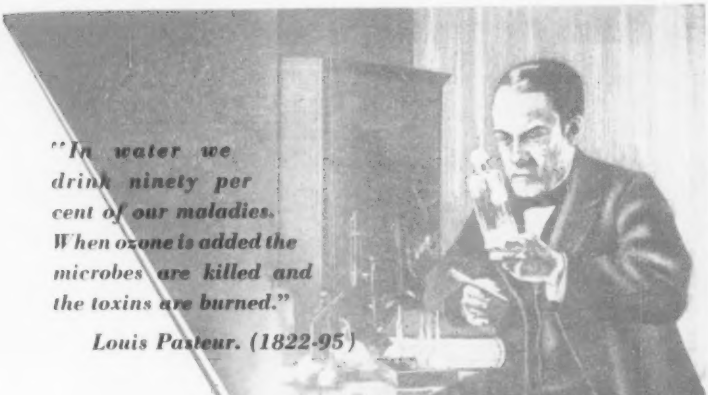
Business_____

Address_____

City_____ State_____



"In water we drink ninety per cent of our maladies. When ozone is added the microbes are killed and the toxins are burned."

Louis Pasteur. (1822-95)

If Pasteur could see a modern Welsbach Ozone water treatment plant, he would add, "... objectionable odors, tastes and colors are eliminated."

Low-cost, efficient Welsbach Ozone will give you complete freedom from complaints about unpleasant taste, odor and color. *And* . . . a Welsbach Ozone plant can pay for itself by eliminating the cost of ordinary chemicals. Add to that these other advantages: no full time supervision or labor; no chemical procurement, handling or storage problems; and, of primary importance, constant and predictable operating costs. In short, Welsbach Ozone water treatment is easily controlled, dependable *and* economical.

Welsbach's research and engineering "know-how" can help you solve your water problems. Just write or phone—we'll be glad to be of service—and without cost or obligation.

WELSBACH OZONE

WILL REMOVE TASTE AND ODOR FROM YOUR CITY'S WATER easily . . . economically

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Parshall

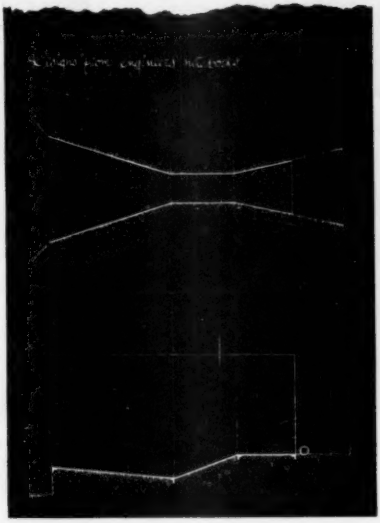
Venturi

Flume

lined with

EVERDUR

for measurement of sewage



Flow measurement in open channels is readily obtained with this Parshall Venturi Flume. It has low head loss and can handle liquids containing solids because the solids can settle at no point. Its accuracy—satisfactory for most waste disposal problems—depends upon maintaining correct dimensions, particularly in the throat.

In providing this flume in the 3 or 4 smallest sizes, with accurate metering equipment, the Simplex Valve & Meter Co. realized that shifting forms, shrinking concrete, and erosion might set up sizable inaccuracies. Their solution was a liner of .1019-in. EVERDUR* (ANACONDA Copper-Silicon Alloy) sheets welded to angle irons set in concrete. Everdur's smoothness prevents solid accumulations where floor slope causes the flow to lose head. Over a long period of time this Parshall Flume will provide true flow measurement with minimum maintenance — thanks to the strength and corrosion-resistance of this built-up, light-weight Everdur structure.

Everdur is produced in practically all commercial forms, including casting ingots. It can readily be cast, forged, formed, machined and fabricated by all the usual methods and is ideal for assemblies such as gates, screens, float chambers, weirs, troughs, manhole steps, gate guides, stems and bolts.

For more information about Everdur, write for Publication E-11 to The American Brass Co., Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

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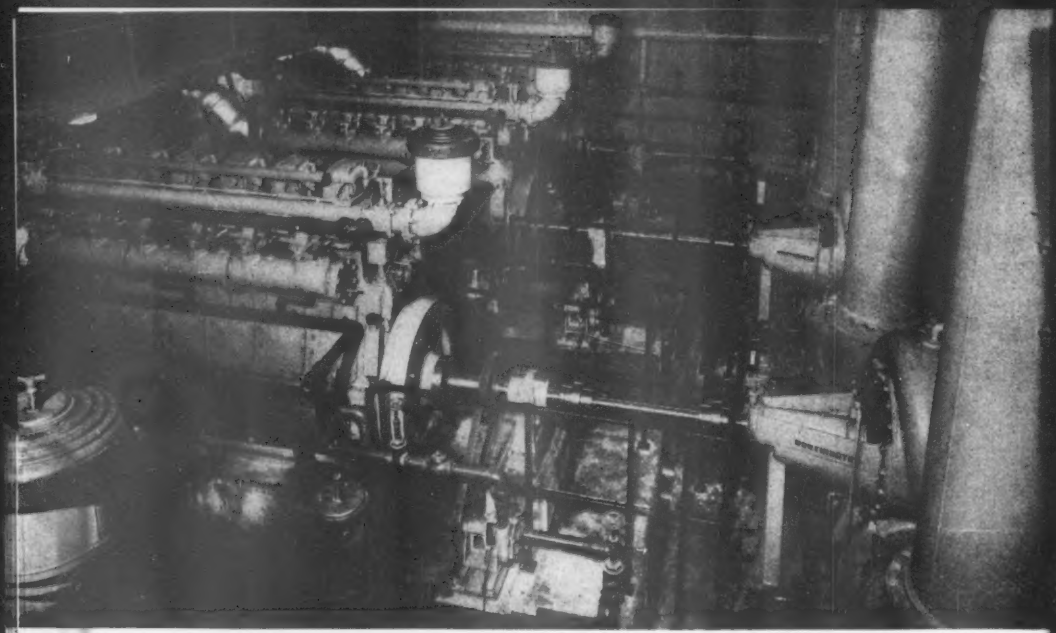
specify Everdur **ANACONDA®** Copper-Silicon Alloys

STRONG • WELDABLE • WORKABLE • CORROSION-RESISTANT



FOUR 20-MGD CENTRIFUGAL PUMPS (right) pump raw sewage into Oklahoma City's South side Sewage Treatment Plant. Worthington Sewage Gas Engines (left) drive pumps. Installation uses three other such pumps for recirculation, also driven by Worthington engines.

An exact match for Oklahoma City's needs

The right *equipment for new sewage plant selected from Worthington's complete line*

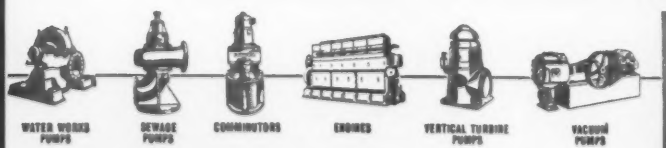
An outstanding job in every way. That's what they're all saying about the new Southside Sewage Treatment Plant at Oklahoma City.

Seven giant Worthington 20-mgd centrifugal pumps used for pumping raw sewage and recirculation are driven by Worthington gas-engines that are fueled by methane gas from raw sewage.

Oklahoma City's modern plant—like virtually every municipal installation—had *special* requirements. They met these requirements with Worthington equipment—engines, pumps, and other apparatus such as air compressors.

To municipalities like Oklahoma City, Worthington means getting *all* major public work equipment under *one* responsibility. Engines for any available fuel, the world's most complete line of pumps, comminutors, air compressors, water treating equipment, motors, and power-transmission equipment.

Write us—learn all the reasons why *there's more worth in Worthington*. Worthington Pump and Machinery Corporation, Public Works Division, Harrison, N. J.



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WORTHINGTON

Public Works Equipment

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This is no fire, officer. We're headin' for Kansas City Missouri and the A.W.W.A. Convention.
See you in Kansas City, friends, May 4 to 9. And don't forget to look in on us at Booths 77 and 78.

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HYDRANTS

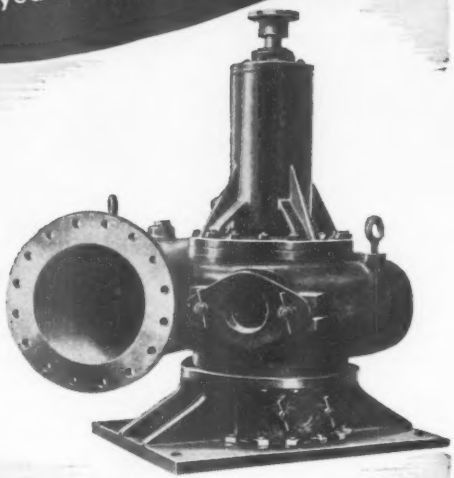
Made by R. D. Wood Company

Public Ledger Building, Independence Square, Philadelphia 5, Pa.

Manufacturers of "Sand-Spun" Pipe (centrifugally cast in sand molds) and R. D. Wood Gate Valves

when it's pumps, think of Economy

backed by over thirty years of specialized experience



The Mixed Flow Volute Pump illustrated is just one of the many types in the extensive line manufactured by Economy Pumps, Inc. Available in capacities to 80,000 G.P.M., it is designed for service where large volumes of liquids are to be handled.

Maintenance expense is held to a minimum. Case records show Economy Pumps operating for fifteen to twenty years without replacement of major parts. However, should repairs be necessary, all parts are renewable.

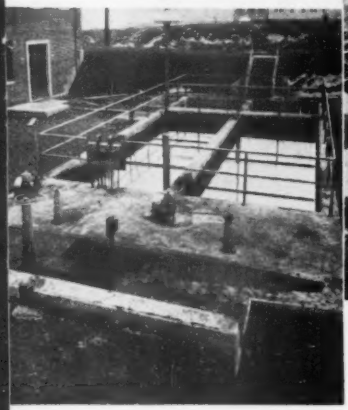
Catalog No. F-1049 gives complete design and construction details. Address Dept. AC-4 for your copy.

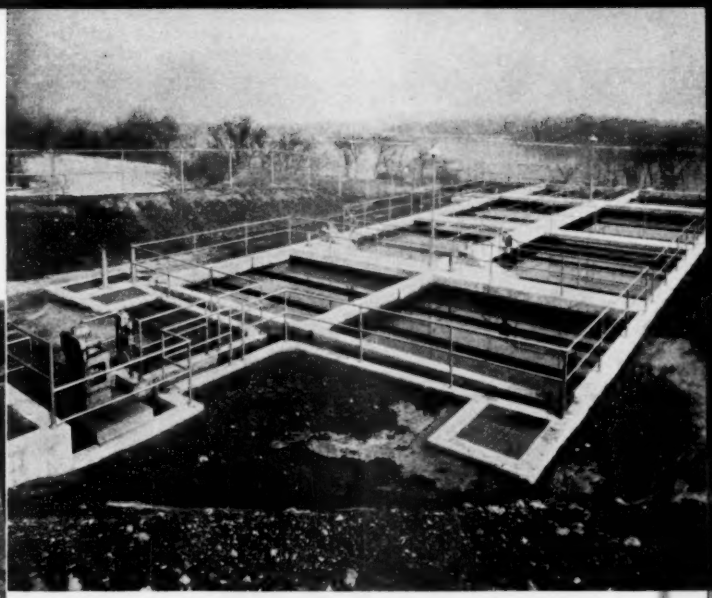
Centrifugal, Axial and Mixed Flow Pumps for all applications

Economy Pumps Inc.

Sedgley Ave. at 19th and Lehigh, Philadelphia 32, Pa.

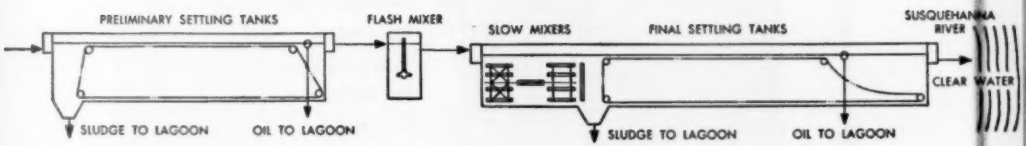
Settleable solids and floating oils are separated in the two 9 x 52 x 6 ft. preliminary settling tanks by L-B Straightline Collectors and Rotoline Skimmers.





Link-Belt flash mixer intimately mixes alum and lime for flocculation. Slow mixing is performed by two L-B mixers, parallel to the flow, whose speed is varied by P.I.V. Variable Speed Drives. Two final settling tanks, 18 x 90 x 8 ft., also have L-B Straightline Sludge Collectors and Rotoline Skimmers.

How to halt stream pollution



Completely LINK-BELT-equipped waste treatment plant removes oil and suspended solids at world's largest freight classification yard

COOPERATING with Pennsylvania's Clear Streams Program, the Pennsylvania Railroad recently completed an efficient waste treatment plant at their Enola (Pa.) yards. Designed by Gannett, Fleming, Corddry & Carpenter, Inc., consulting engineers, the plant is laid out for an average flow of 2.0 mgd, with a 4.0 mgd maximum storm flow.

To separate efficiently the solids and oils resulting from locomotive washing, ash quenching, sanitary sewage and storm water, surface loading is carefully controlled. At design flow, the preliminary tanks are limited to 2140 gal. per sq. ft. per day . . . the final tanks to 260. Sludge and oil removed are lagooned.

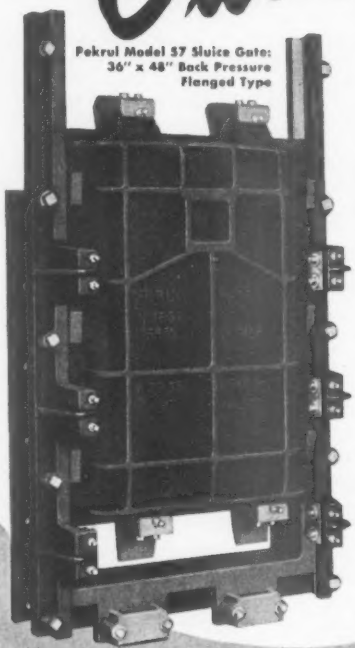
Whether it's for a compact industrial waste plant or a large metropolitan water or sewage treatment works, you'll find it pays to rely on Link-Belt equipment. Our sanitary engineers will work with your consultants and chemists —help you get the best in modern water, sewage or industrial liquids treatment.

LINK-BELT COMPANY: Chicago 9, Indianapolis 6, Philadelphia 40, Atlanta, Houston 1, Minneapolis 5, San Francisco 24, Los Angeles 33, Seattle 4, Toronto 8, Springs (South Africa). Offices in principal cities. 12,500-A

LINK-BELT

SANITARY ENGINEERING EQUIPMENT

Pekrul Gates



Pekrul Model 37 Sluice Gate:
36" x 48" Back Pressure
Flanged Type

PEKRUL GATES are engineered to meet the most rigid requirements for:

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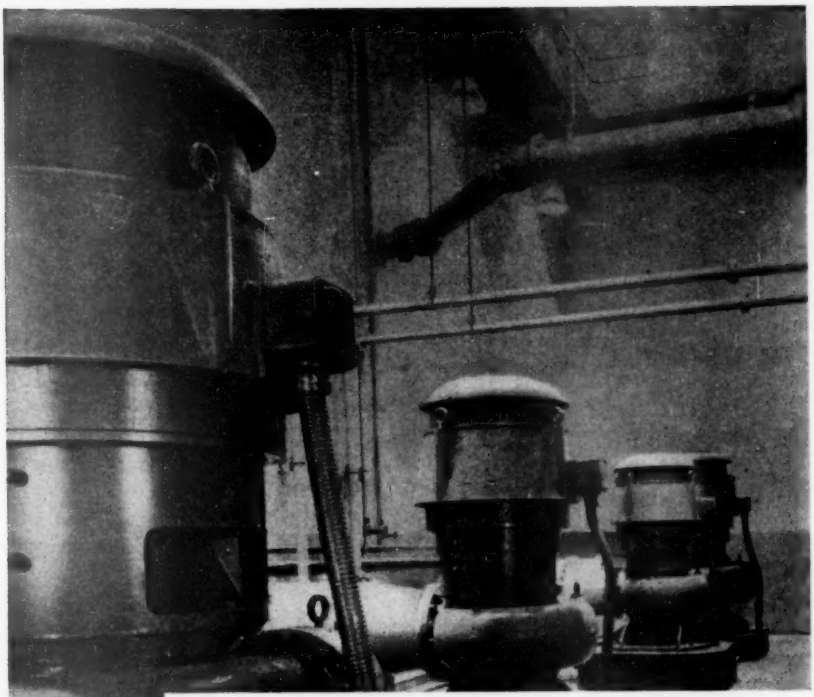
- Fish Hatcheries
- Rearing Ponds
- Recreation Pools
- Cooling Towers
- Steel Mills

PEKRUL GATE DIVISION

MORSE BROS. MACHINERY
DENVER, COLORADO

Write for Catalog 49



Keep This Angle in Mind

. . . that when you want to move big volumes of sewage or storm water *economically,* your best bet is Fairbanks-Morse *Angle*flow Pumps. Designed for maximum plant efficiencies where large quantities must be pumped against moderate heads, these dependable pumps give you a new high in service . . . a new low in operating and maintenance costs. Wide, unobstructed passages through impeller and volute make them especially suitable for handling debris-filled water. Sizes range from 8 to 54 inches . . . capacities up to 80,000 g.p.m. For complete information see your local Fairbanks-Morse Branch or write Fairbanks, Morse & Co., 600 S. Michigan Ave., Chicago 5, Ill.

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PUMPS • DIESEL LOCOMOTIVES AND ENGINES • ELECTRICAL MACHINERY • SCALES
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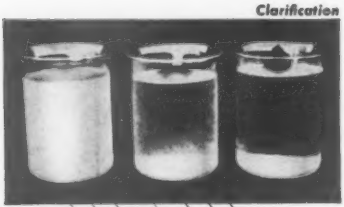
SEWAGE PLANT OPERATORS

For Clarification or Sludge Drying

INVESTIGATE THE ADVANTAGES

IN USING *GENERAL CHEMICAL* "ALUM"

Clarification



Above photograph illustrates effective coagulation and clarification of turbid waste by means of General Chemical Alum.

Clean and easy to handle

Dry feeds well or dissolves readily for solution feeding

Requires only low-cost feeding equipment and minimum attention

Helps sludge digest readily

Speeds sludge drying with minimum odor

Produces clear, low-color effluents

Reduces chlorine consumption in effluent

Economical to use

Sludge Drying

Above: Sludge bed treated with General Chemical Alum to hasten dewatering.

BASIC CHEMICALS

GC

FOR AMERICAN INDUSTRY

Wherever your plant may be—America over—you will find General Chemical "Alum" is always the same high quality . . . always uniform . . . always readily available from coast-to-coast producing and shipping points. To you, that means increased efficiency, stepped-up economy in your clarification and sludge drying operations. So be sure. Get the best; specify General Chemical "Alum"—the *preferred* "Alum."

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ALLIED CHEMICAL & DYE CORPORATION

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Circular Collectors

Types for every waste treatment problem

- DESIGNED FOR EFFICIENT LONG-TERM OPERATION
- ENGINEERED FOR USE IN CIRCULAR OR SQUARE TANKS
- SELECTION OF DRIVES TO MEET YOUR SPECIFICATIONS
- CLARIFLOW THICKENERS FOR FLUE DUST CLARIFICATION

TRACTOR DRIVE COLLECTOR

This pier-supported collector is designed for circular tanks. The rotating bridge acts as the lever arm rotating a sturdy center cage which carries the collector arms. Rotational force is provided by a two-wheeled, rubber tired tractor unit running on the rim (or effluent weir wall of the tank). Drive unit is simple, easily accessible, and not affected by snow or ice.

SUSPENDED COLLECTORS are used where a simple bridge can span the tank diameter. In this case, the complete motor and drive assembly, together with the drive tube and collector arms, are suspended from the bridge.

WRITE FOR BULLETIN 9W65

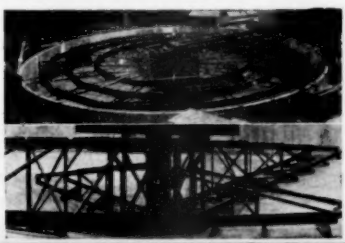
CLARIFLOW THICKENER

This unit utilizes the principles of fluid mechanics, so highly developed in Walker sedimentation units. It removes all settleable solids and remarkably clarifies the flow. All parts are sturdily built . . . designed for the "tough" jobs.

WRITE FOR BULLETIN 10169

PIER DRIVE COLLECTOR

The Pier Drive Collector is recommended where it is undesirable to operate a Tractor Drive . . . where the access bridge must be stationary, or the corners of square tanks must be scraped. Center drive mechanisms, ranging from 1/2 to 10 horsepower, are built for long life and heavy duty service. Worms are carburized and ground steel and precision meshed with hardened bronze worm wheels. The balls run in hardened, ground, renewable ball races.



PROQUIP PROCESS EQUIPMENT

WALKER PROCESS EQUIPMENT INC.

FACTORY • ENGINEERING OFFICES • LABORATORIES

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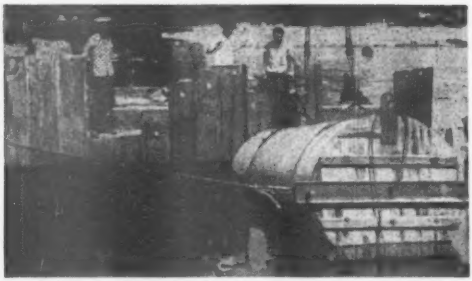


Installing concrete pipe for river and land sections of new Tampa sewer line. Greeley and Hansen, Chicago, engineers.

In building for the year 2000 Tampa chooses CONCRETE PIPE

To eliminate pollution of its river and bay waters, Tampa, Fla. built an extensive new sewage system. Designed for the future, it will serve a metropolitan area population in the year 2000 expected to be nearly three times greater than Tampa's present population.

New facilities include intercepting sewers, pumping stations, force mains, lateral sewer extensions, six crossings beneath river and harbor channels, a treatment plant with a 36 mgd primary treatment capacity, and a subaqueous outfall. Almost 18 miles of concrete pipe were used.

Like Tampa, hundreds of other cities have chosen concrete pipe for sewers because in thousands of installations it has demonstrated rugged durability, great structural strength, minimum infiltration and leakage, maximum hydraulic capacity and tremendous resistance to wear from abrasive matter. Concrete pipe is moderate in first cost, requires little or no maintenance, serves longer. Result: ***low annual cost.***

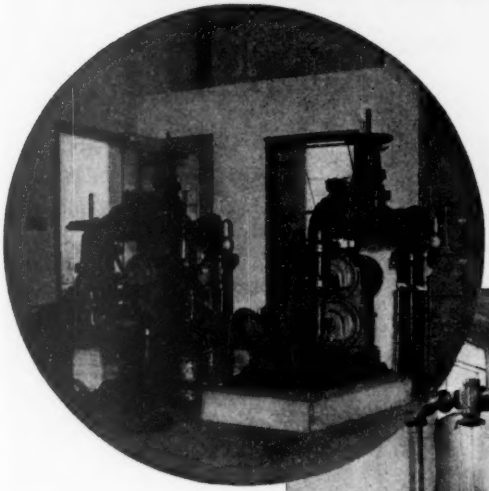
PORTLAND CEMENT ASSOCIATION

33 W. Grand Ave. / Chicago 10, Ill. / A national organization to improve and extend the uses of portland cement and concrete through scientific research and engineering field work

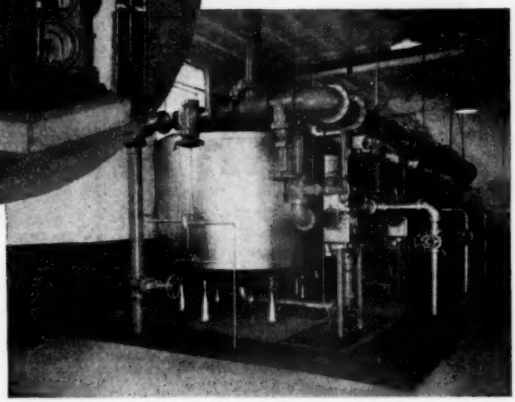
Engineers Smith and Gillespie *specify*

INERTOL PAINTS

for these sparkling Florida plants



Glamortex—an alkyd resin enamel—adds a glossy mar-resistant finish to machinery, railings, piping and non-submerged metal surfaces in Orlando's Sewage Treatment Plant. Sturdy *Inertol Standard Thick* protects submerged metal surfaces.



Metal surfaces throughout the Jacksonville Beach Water Softening Plant retain a lasting high-gloss finish with *Glamortex* and *Ramuc Utility* Enamels. And their superior performance means long-range economy as well.

Jacksonville, Florida, engineers choose INERTOL coatings developed especially for water works and sewage plants

● When "specification" time rolled around, Consulting Engineers Smith and Gillespie selected Inertol Paints to keep these Florida installations protected and bright looking. Following Inertol recommendations, they discovered Inertol coatings that met their exact requirements for hardness, elasticity, weather-resistance, etc.

Each product in the broad Inertol line has been proved in thousands of installations in all parts of the country. Our Field Technicians will gladly discuss the superior performance and substantial economy of the Inertol line. Send today for our free "Painting Guide," prepared especially for Consulting Engineers, Design Engineers and Specification Writers. It indicates the most suitable type coating for every surface. Plant Superintendents and Contractors will also find it invaluable. You'll refer to it time and again!

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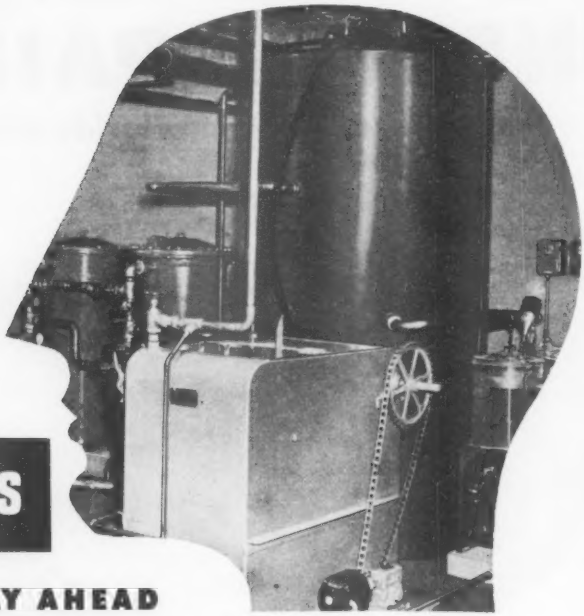

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WAY AHEAD

in water treatment

Here's a complete water works in a small package—the JBAS—for Field Crew Drinking Supply, Engine Cooling, Boiler Feed, Small Domestic Supplies, Chemical and Manufacturing Process.

The source of water doesn't matter. JBAS versatility has been demonstrated in hundreds of installations treating 5 to 100 gallons per minute... equally effective for softening, clarifying and sterilizing or removing organic matter, tastes and odors... providing a water supply to meet the most exacting standards.

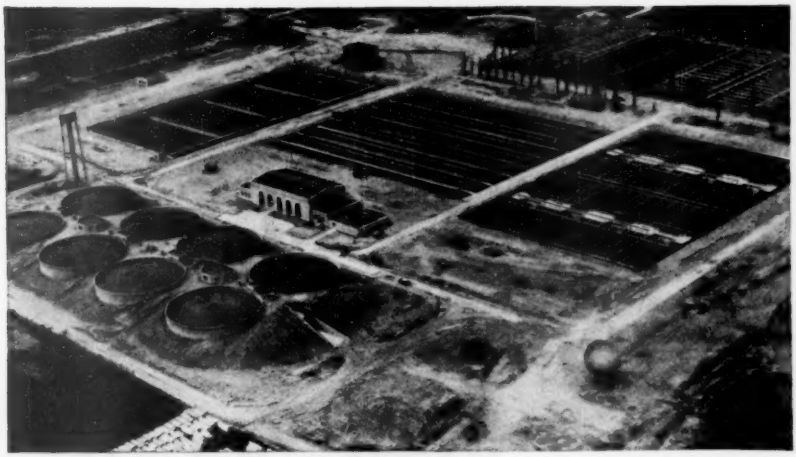
A JBAS gives you control of water quality with little supervision. It conserves space, reduces installation costs. A JBAS can be readily moved if necessary. Write today for complete description—Bulletin 1845.

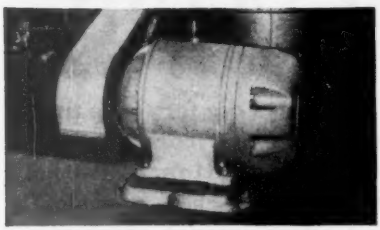
INFILCO since 1894

INFILCO INC. *Tucson, Arizona* | *Plants in Chicago & Joliet, Illinois*

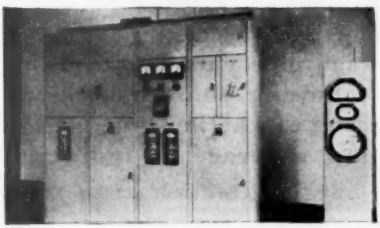
FIELD ENGINEERING OFFICES IN 26 PRINCIPAL CITIES

World's Leading Manufacturers of Water Conditioning and Waste Treating Equipment

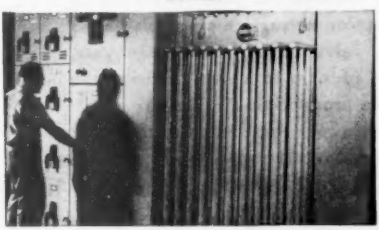




Motors



Control



Unit Substations

G-E application engineers select products like these to form the co-ordinated electrical system that exactly fits your plant requirements.

Here's Help on Your Campaign for

CLEAN WATERS

General Electric helps make your pollution-control program a success in three ways:

1. Aids you in winning public support through the G-E packaged program "Modern Sewage Treatment" including the color sound movie *Clean Waters.*

2. Assists your engineers or consultants in the formation of electrical plans.

3. Manufactures a complete line of dependable electric equipment for sewage treatment plants.

To take advantage of this complete, three-way service, contact your G-E representative ***early in the planning stage*** when he can help you most. ***General Electric Co., Schenectady 5, N. Y.***

GENERAL ELECTRIC

666-69

to aid peak
defense production

Collect and Sell your Iron and Steel Scrap

Mr. Q-Check says *dig* for scrap metal —*search* every nook and corner of your pipe yard—*scrape* the bottom of the barrel! For iron and steel scrap is critically needed to aid peak defense production in steel mills and iron foundries.

The average pipe yard has some or all of the following sources of scrap metal, according to whether pipe is used for water, gas, sewerage or industrial service:

Obsolete fittings; cut pipe (short pieces of distribution or service pipe); damaged hydrants, valve boxes, manhole covers, etc. It all adds up to a vital contribution to defense production.

Collect your scrap now. Phone your nearest scrap dealer. He wants what you have *but quick*, and pays good cash prices.

CAST IRON PIPE RESEARCH ASSOCIATION . . . CHICAGO

SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 24 | APRIL, 1952 | Number 4

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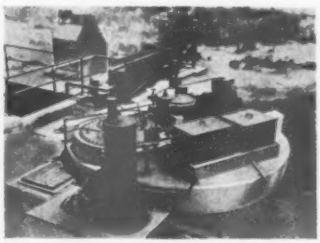
VERSATILE...

is the word for the Dorrco Vacuator*

Here are Three Ways it can be utilized to solve your problems . . .

AS A PRE-TREATMENT UNIT

1 At overflow rates of 5000 to 7500 gal./sq. ft./24 hrs., the Vacuator can serve as a complete pre-treatment unit, removing scum, grit and a substantial percentage of suspended solids—also thickening excess secondary sludges.



EXAMPLE:

At McAlester, Oklahoma's new West Sewage Treatment Plant a 12' dia. Vacuator removes scum, grease and grit from incoming screened sewage, prior to two-stage trickling filter treatment. Operating results show removals of 46.6% of suspended solids and a 28.4% reduction in B.O.D.

AS A SCUM-REMOVAL UNIT

2 At overflow rates of 5000 gal./sq. ft./24 hrs., the Vacuator can be used for the treatment of oil, cannery, packing house, laundry and similar tough-to-handle wastes.

EXAMPLE:

Scum-forming cannery wastes virtually put the Palo Alto, California Sewage Treatment Plant out of commission five months of the year. A 35' dia. Vacuator, followed by secondary treatment, completely solved the problem by removing an average of 43.6% of suspended solids, 58% of settleable solids and 8.4% of B.O.D. during the canning season.

AS A GREASE-REMOVAL UNIT

3 Overflow rates as high as 10,000 gal./sq. ft./24 hrs. can be used when the primary function of the Vacuator is grease removal from domestic or industrial wastes.

EXAMPLE:

At Patuxent River, Maryland, a 14' dia. Vacuator removes heavy "slug loads" of grease ahead of primary treatment. Removals average 50% of suspended solids and a 51% reduction in B.O.D., enabling the standard Dorr Clarifier which follows to function smoothly without auxiliary equipment.

These examples illustrate but three of the many ways in which the compact, three-product Vacuator is successfully solving difficult problems. If you think vacuum-flotation could help you, write for Bulletin #6301.

*Reg. U.S. Pat. Off.

DORRCO

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Sewage Works

EXPERIMENTAL STUDIES ON THE CONCENTRATION OF RAW SLUDGE *

By J. F. Laboon

Consulting Engineer and Chairman, Board of Allegheny County Sanitary Authority, Pittsburgh, Pa.

One year of laboratory research has been confirmed by one year of pilot plant operation to demonstrate that the concentration of raw sludge by flotation through biological means aided only by temperature and time controls is practical and can yield average daily solids concentrations of 20 per cent and, in addition thereto, can produce a sludge which can be dewatered successfully on a vacuum filter without the aid of conditioning chemicals. Furthermore, a short period of digestion experiments on concentrated sludge at the pilot plant offers support to Keefer's (1) conclusion that concentrated sludge can be digested successfully. This would result in great savings in cost of installation and operation of digestion tanks, sludge beds, and vacuum dewatering.

Concentration of sludge in the raw, activated, and digested states has been the subject of much study, discussion, and writing, particularly in the case of activated sludge, which is produced in large quantities with high moisture content. The high moisture content of activated sludge has served to point to the need for concentrating it in order that costly sludge disposal facilities may be reduced in size and cost and even simplified. The cost of installation and operation of digestion facilities, with the difficulties due to great quantities of supernatant, may be reduced almost in proportion to reduction in moisture content of the raw sludge. Dewatering facilities likewise are expensive and troublesome, whether the sludge is to be dried and prepared as a fertilizer or incinerated, either in the raw or digested form.

In the preparation of the comprehensive report for the Allegheny County Sanitary Authority issued January, 1948, and in the subsequent activities in the preparation of design plans and specifications for the Pittsburgh project, which is to serve 63 municipalities, including the City of Pittsburgh, and estimated to cost $60,000,000, the sewage treatment facilities have been studied with a view to producing a plant which would be simple in form yet most economical under the conditions that a 50 per cent removal of B.O.D. was to be obtained in the initial installation.

Early studies lead to the conclusion that the simplest and most economical layout should include provisions for incineration of sludge, whether in the raw or digested state. A plant for the incineration of raw sludge would be simpler in form than one providing for digestion and incineration of sludge as well as power generation from the gases produced by digestion. Later studies developed that the most economical

* Presented at 24th Annual Meeting, Federation of Sewage and Industrial Wastes Associations; St. Paul, Minn.; October 8–11, 1951.

project, as well as the one involving the simplest layout for operation, should include facilities for the dewatering and incineration of raw primary sludge. Yet this type of plant could be made simpler and less involved if the costly and troublesome dewatering facilities (by means of vacuum filters) could be replaced with facilities for sludge concentration so that the concentrated sludge might be incinerated directly without mechanical dewatering. Furthermore, if the concentration of sludge could be accomplished without the aid of chemicals, an important step would be made toward further simplifying the design and operation of sludge disposal facilities.

A search revealed that two sewage treatment plants in Ohio were incinerating sludge directly without mechanical dewatering and without the aid of coagulating or conditioning chemicals; namely, Ashland (2) and Piqua. Both are makeshift operations from this standpoint. Ashland originally installed vacuum filters for dewatering purposes and a multihearth incinerator for the disposal of the dewatered sludge. However, when small plant difficulties with complicated operations of this kind develop and it becomes necessary to store raw sludge so that repairs to the dewatering equipment can be made, or whenever hard-to-find and costly conditioning chemicals become a real problem, as during the last war, things begin to happen. It was observed at Ashland that the sludge in the storage tanks had partially floated and concentrated without artificial aid so that by withdrawing the subnatant and supernatant, which had formed in lenses, thus dropping the concentrated sludge to the bottom of the tank, the sludge could be pumped directly to the incinerators for disposal. Although supplementary fuel was necessary for proper combustion, the over-all cost was warranted under the circumstances; from that time on, dewatering by means of vacuum filtration was abandoned. In 1948, the average sludge concentration at Ashland over two test periods made by the Sanitary Authority, totaling five days, was 15 per cent. (The test periods exclude one day when a bypass valve was left open and dilute raw sludge from the primary tanks was accidently admitted to the incinerator.) The Piqua plant is said to produce a sludge concentration of about 10 per cent before incineration. Neither of these plants added heat to the concentrating sludge. Also no attempt was made to control concentration on a time basis.

Extensive studies of the Ashland operation, supported by laboratory research made by the Authority, led to the finding that there was nothing unusual about the character of the Ashland sewage and sludge to cause concentration by flotation and that sludges from sewage treatment plants in the Pittsburgh district reacted similarly. Laboratory studies were then conducted on raw sludges obtained from treatment plants located at Ashland and Cleveland, Ohio, and Uniontown, Butler, Penn Township, and Waynesburg, Pa. The studies were made at various temperatures from 20° to 60° C. with various periods of concentration ranging from 1 to 11 days. It developed that 35° C. was the optimum temperature and 5 days was the most economical period of concentration in conjunction with this temperature. The laboratory results were confirmed later in a pilot plant, which was started in operation by the Sanitary Authority in September, 1950.

Other Evidence of Sludge Concentration

Much has been written about concentration of sludges by settling. However, because this paper is devoted exclusively to the concentration of sludges by flotation, reference generally is given only to those articles and patents dealing with concentration of sludge by flotation.

Irwin (3) has patented a method of concentrating digested sludge by flotation caused by the addition of chemicals. The sludge is drawn off the bottom of the tank after the subnatant is removed and then powdered and used as a fertilizer.

The Peck (4) patent is based on the flotation of activated sludge in the presence of aerobic bacteria aided by heat and the addition of sulfuric acids or other chemicals to promote the evolution of gas, which causes the solid matter to rise to the surface of the tank.

Kelly (5) claims to produce flotation by application of vacuum to an encased body of liquid suspension with continuous removal of floating particles. The liquid must be gas-containing (compressed air or CO_2).

Green (6) in his patent uses a "solids concentrating chamber" on the roof of a digester. Raw sludge is passed to the solids concentration chamber in suspension in a substantially constant stream where aerobic conditions are preferred. The sludge thickens, settles, and passes into the digestion tank below; the supernatant is withdrawn to the clarifier. No mention is made of flotation, but the descriptive matter in the patent papers obviously refers to compacting by settling. No heat or time control is used.

An editorial (7) as early as 1931 stated "Another marked improvement in digestion of sludge would be available if fresh solids could be so concentrated before entering the digestion tank that it would be unnecessary to draw off supernatant liquor . . . it is undoubtedly desirable to reduce the volume of supernatant liquor as much as possible by preliminary concentration of incoming solids."

Pearse (8) in 1924 pointed out that activated sludge was coagulated with or without heat and floated for ready removal; Fort Worth, Tex., Urbana, Ill., and New Britain, Conn., are cited as examples. Solids concentrations of 10 to 15 per cent were obtained at New Britain.

Downes (9) in 1934 reported concentration of digested sludge by flotation by the addition of chemicals, which caused coagulation and gasification. The sludge was raked off at the top and the liquor was withdrawn at the bottom on a continuous basis.

Rudolfs (10) in 1943 wrote on the concentration of activated sludge by treatment with acids, which caused flotation. He also reported on results obtained on concentration of activated sludge by treatment with calcium hypochlorite and stated that turbid liquors can be clarified by treatment with acids or iron coagulants. Rudolfs points out that chemically treated activated sludge floated with equal facility whether or not inert materials were added and that the gas is intimately held, and with a considerable force, by the sludge. The article develops that gases produced by biological activities are of importance and that CO_2, particularly, can be used to enhance flotation.

Goudey, Keefer, Rudolfs, and Donaldson (11) in a symposium on "Concentration of Sewage Sludge" reported on findings at Los Angeles, Baltimore, Elizabeth, N. J., and New York City, respectively; Goudey on settled activated and fresh solids, Keefer on settled waste activated sludge, Rudolfs on settled fresh solids which were barged to sea, and Donaldson on settled digested and activated sludge. Rudolfs makes the observation that the "Compaction of activated sludge has been the subject of experiments over several years, using chemicals, inert materials, poisons and gases. In studies on flotation it was indicated that a dense sludge can be produced by the use of calcium hypochlorite. The initial concentration does not appear to be important, but the degree of oxidation and size of floc are both factors." He also states "In the concentration of sludges, the character of the sludge is of great importance. The initial concentration, time

and temperature have varying effects on fresh, activated and digested solids." Rudolfs also wrote in detail on the Elizabeth, N. J., results of concentration by settling (12).

Krause, at Peoria, Ill., developed a method of concentrating activated sludge by reaeration of partially digested activated sludge mixed with digested primary sludge causing flotation of solids, which were removed continuously from the top by means of a screw conveyor attached to the skimming mechanism of the clarifier. This produced a concentration of 8 to 10 per cent. It is said that the process has been abandoned as being uneconomical.

Rudolfs and Logan (13) in 1943 cited a number of factors, which have been confirmed by the pilot plant studies made at Pittsburgh. The authors reported laboratory experiments on the concentration of raw and digested sludge by flotation by means of heat and time. It was found that 37° C. was the optimum temperature for raw sludge and 55° C. for ripe sludge; that fresh solids float, but continue to compact, whereas ripe sludge sinks; that compacting of the sludge takes place at the surface of the liquid; that the floating and subsequent compacting appears to be related to the activities of gas-forming (mainly CO_2) organisms; that after a period of 120 hr. of compacting, the temperature effect is more pronounced than after 96 hr.; that continued time of compacting does not increase appreciably the final concentration at the supposedly optimum temperature of 37° C.; that the concentration reached after a given time of compacting at a definite temperature depends upon the initial concentration of the solids; that floating of sludge may be a desirable method of compacting for ultimate sludge disposal, but becomes detrimental to purification of the liquor when allowed in settling tanks; and that the practical significance of inducing increased sludge concentration is obvious for digestion, sand bed drying, vacuum dewatering, and incineration.

Rankin (14) in 1948 stated that "Consideration must also be given to the percentage of volatile matter in the solids, percentage digested, and, most important of all, the water content of the sludge." The further observation is made that the best place to thicken sludge is ahead of the digester, preferably in the primary sedimentation tanks. The author gives curves for wet sludges ranging from 1.6 to 12 per cent dry solids to indicate that the digester capacity in this range varies directly in proportion to the solids concentration of the raw sludge. Thus, a raw sludge with a concentration of 12 per cent solids would require one-half the digester size that a 6 per cent sludge would require.

Keefer (1) produced experimental data to show that concentrated sludge can be digested successfully with a gradual increase in the digestibility of the sludge as its moisture was increased from 67.5 to 85.1 per cent (32.5 to 14.9 per cent solids).

Laboratory Studies on Sludge Concentration

Laboratory studies at Pittsburgh on concentration of raw sludge and the effect of volatile matter, initial solids content, temperature, and time, prior to the installation of the pilot plant, involved 214 samples of various sludges taken from six sewage treatment plants, as already enumerated. Experiments on concentration of mixtures of raw and activated sludges from the Cleveland, Ohio, and Penn Township, Pa., sewage treatment plants were conducted on 10 samples with varying success.

After it was found that raw sludge from various sources could be concentrated satisfactorily, the principal work of the laboratory was directed toward finding the optimum temperature at which the highest concentra-

tions could be developed in the shortest time. In this series of tests the time and temperature effects were determined from the standpoint of practical results, after which the character of the raw sludge was studied to determine, if possible, the factors which would retard concentration by flotation. It was found that volatile solids and pH were the most important factors affecting concentration by this method. None of the tested sludges contained inhibitive values with respect to volatile solids and pH except when grit chambers failed to function properly, thus causing the volatile solids to fall to a 50 per cent content or even less, as was found on occasion with raw sludge from a certain sewage treatment plant. Raw sludges, even with a 50 per cent volatile solids content, were concentrated successfully except when there was an excess of heavy silt, which served to drown out almost completely all bacterial action. It was found that samples with unusually low volatile content, when concentrated by flotation, were quite sensitive to movement, which in time caused part of the sludge to settle to the bottom. Values of pH sufficiently high to inhibit bacterial action will also inhibit concentration by biological flotation.

The first concentration determinations were made with Imhoff cones and later with 2-gal. jugs, 2-in. and 4-in. glass tubing in various lengths, and, finally, 10-ft. and 20-ft. sections of 6-in. glass pipe. Another set of experiments was conducted in 50-gal. drums open at the top. The 20-ft. length of 6-in. glass pipe was used to determine the effect, if any, of hydrostatic pressure on the upward movement of sludge when concentrated by flotation. It was observed that the column of sludge when rising to the top showed signs of retardation due to adherence to the sides of the glass tubes and pipes, which steadily increased as the sludge compacted and thus exerted greater pressures on the side of the container. Large vessels would permit freer upward movement of rising sludge by the elimination of most of such side friction. This may have been one of the factors which produced lower concentrations in the laboratory experiments than were actually developed in the pilot plant operations. The initial depth of raw sludge (in a 20-ft. height of glass pipe) seemed to have no effect on the degree of concentration, neglecting the effect of side friction.

Temperature Studies—Raw Sludge

Temperatures were studied in steps of 5° from 20° to 60° C.

Raw sludge was concentrated by flotation at 20° C., but it usually took 48 hr. before the sludge began to rise as compared with complete flotation in less than 24 hr. with preheated raw sludge at the optimum temperature of 35° C. As the temperature becomes greater, specifically at 55° and 60° C., the evolution of gas is so rapid as to keep the sludge in active suspension, thus preventing compaction by flotation and causing the gases to escape from the sludge. The sludge will rise to the top, but fall back in a short period of time as the gases escape. Table I illustrates the effect of temperature at 60° C. on raw sludge over a period of 120 hr. The sludge floated completely at the end of 2 hr., but began to settle an hour later. At the end of 120 hr. approximately 10 per cent of the sludge was on the bottom and the rest on top.

Table I also gives the similar data with the same raw sludge at 22° C., also for a 120-hr. period. In this case 0.5 per cent of the sludge was on the bottom at the end of the period.

Figure 1 shows curves giving concentrations at the end of 120 hr. with the same sludge at various temperatures. Two sets of curves are shown for two different sludges on different days. Figure 2 gives the result of concentration of a sludge containing an average of 50.5 per cent volatile solids at various times of concentration ranging from 48

TABLE I.—Effects of Temperature on Concentration

Sample[1]	Time After Filling (hr.)	Temp. (° C.)	Supernatant (ml.)	Subnatant (ml.)	Settled Solids (ml.)	Floating Solids (ml.)
Penn Twp. .	0	22	0	0	0	0
	2	22	60	0	940	0
	3	23	75	0	925	0
	6	24	100	0	900	0
	48	23	100	0	900	0
	120	22	0	400	3	650[2]
Penn Twp.	0	60	0	0	0	0
	2	60	0	14	0	991
	3	60	0	50	0.3	995
	5	60	0	130	0.7	873
	6	60	0	239	1	761
	48	60	0	245	2	753
	120	60	0	435	65	500

[1] Sludge is the same raw sludge at both 22° C. and 60° C.; both tests begun Nov. 23, 1949.
[2] Volume increased.

to 120 hr. at 35° C. This illustrates the possibility of concentrating by flotation, sludge containing an unusually low volatile solids content. This sludge, due to its unusual character, concentrated almost to the maximum within 48 hr., which is not to be expected with high-volatile sludges.

In the laboratory tests in temperature ranges of 30° to 40° C. and with volatile solids greater than 50 per cent in the raw sludge, all of the sludge floated and none was left on the bottom of the container, except in rare instances.

Concentration of Activated Sludge

Activated sludge, without admixtures, would not concentrate by flotation. The sludge turned septic within a few hours after being placed in the containers and settled to the bottom. Activated sludge containing 0.4 per cent solids concentrated to 4.5 per cent solids after settling within 24 hr.

Samples of Cleveland, Ohio, and Penn Township, Pa., activated sludge were mixed in a proportion of two parts of activated and one part of primary sludge by volume and placed in containers to concentrate at various temperatures. The Cleveland activated sludge mixed with primary activated sludge at 31° C., concentrated from 3.4 per cent total solids in the initial mixture, to 6.1 per cent total solids in 120 hr. At the end of the 24 hr. approximately 70 per cent of the sludge had floated and the remainder was on the bottom. The sludge continued to settle until at the end of the fourth day, when all of the sludge was on the bottom.

Penn Township activated sludge mixed with raw sludge in the above-mentioned proportions was concentrated at 25°, 30°, 35°, and 55° C. for a period of 72 hr. The mixture at 25° C. concentrated from 1.8 per cent to 6.3 per cent at the end of 72 hr. with all of the sludge floating. The mixture at 30° C. concentrated from 1.7 per cent to 5.5 per cent at the end of 72 hr. with all sludge floating. Concentrations at 35° C. and 55° C. were practically in the same ratio as the 25° C. samples except that only part of the sludge was floating in each case. At 35° C., only 40 per cent of the sludge was floating and at 55° C. only 10 per cent of the sludge was floating at the end of 72 hr.

A second group of samples was tested in the laboratory at Cleveland by the Authority chemist in June, 1950, when

raw sludge from the Easterly plant and mixtures of concentrated activated sludge and primary sludge were subjected to concentration at 35° C. The primary sludge from the Easterly plant, containing an initial moisture content of 3.5 per cent and volatile at 75.1 per cent, was concentrated at the end of 72 hr. to 15.2 per cent and a volatile content of 72.2 per cent. No sludge remained on the bottom at the end of the period. A mixture of these two sludges in the proportion of two parts of activated sludge and one part raw sludge, producing an initial total solids of 3 per cent and a volatile content of 63.3 per cent, concentrated at the end of 72 hr. to 9.4 per cent and a volatile content of 56.9 per cent. The concentrated activated sludge had an initial total solids content of 2.8 per cent and volatiles of 56.9 per cent. All of the sludge had floated at the end of 48 hr. Only 5 per cent of the sludge remained on the bottom at the end of 72 hr. A sample of activated sludge after it had been pumped from the Easterly plant to the Southerly plant, containing 2.6 per cent total solids and 44.6 per cent volatiles, was concentrated in 72 hr. to 6.2 per cent total solids. A mixture of two parts of raw sludge and one part of activated sludge, after being pumped to the Southerly plant with an initial total solids content of 4.1 per cent and volatiles of 49.9 per cent, concentrated at the end of 72 hr. to 15.1 per cent total solids with a final volatile content of 65.5 per cent. This mixture floated entirely at the end of 24 hr., but at the end of 48 hr. some sludge began to settle and totaled about 5 per cent at the end of 72 hr.

Concentration of Sludge from Large Treatment Plants

During the summer of 1951, the Authority's chief chemist visited Minneapolis, Minn., Chicago, Ill., Detroit, Mich., Cleveland, Ohio, and Buffalo, N. Y., where, with the aid of plant

TABLE II.—Analyses of Raw and Concentrated Sludges (5-Day Concentration at 35° C.)

Plant	Sludge	pH	Alk. (p.p.m.)	Total Solids		Subnatant Liquor				
				(%)	Vol. (%)	pH	Alk. (p.p.m.)	B.O.D. (p.p.m.)	Susp. Solids (p.p.m.)	Susp. Solids Vol. (%)
Minneapolis-St. Paul	Raw	5.6	1,090	8.6	56.7	—	—	—	—	—
	Conc.	5.8	4,400	20.8	51.8	5.2	1,380	—	500	80.8
Chicago Southwest	Raw	6.0	—	5.6	62.4	—	—	—	—	—
	Conc.	5.8[1]	—	14.1[1]	60.0[1]	5.3	1,536	—	306	78.4
Detroit	Raw	5.9	—	9.0	54.6	—	—	—	—	—
	Conc.	6.6	—	14.8	51.0	7.0	1,920	—	1,050	55.5
Cleveland Easterly	Raw	5.7	—	7.1	69.8	—	—	—	—	—
	Conc.	6.0	—	17.9	67.7	5.7	1,530	3,950	520	68.3
Cleveland Southerly[2]	Raw	6.6	—	5.9	47.0	—	—	—	—	—
	Conc.	7.1	—	10.1	44.8	7.2	2,412	1,800[3]	2,440	48.9
Cleveland Easterly	Raw	6.5	—	4.2	64.7	—	—	—	—	—
	Act.	6.7	—	3.3	61.6	—	—	—	—	—
	Conc.	7.0	—	5.3	55.8	7.5	3,450		465	57.2
Buffalo	Raw	5.9	640	9.0	63.8[4]	—	—	—	—	—
	Conc.	5.1	2,480	22.5	60.9	5.0	752	—	326	86.2

[1] Top sludge; bottom sludge values were 6.3, 8.7, and 60.1, respectively.
[2] Imhoff sludge.
[3] Depletion 15 per cent.
[4] Raw sludge grease 23.9 per cent, on dry weight basis.

operators, he collected samples of sludge, which he immediately brought to Pittsburgh for analysis and concentration. The results are given in Table II, with additional comments as follows:

Minneapolis-St. Paul

The entire volume of raw sludge floated within 24 hr. and none of the sludge had settled out at the end of 120 hr. The subnatant liquor was colored an opaque tan. It is to be noted that the volatile solids content in the raw sludge on this occasion was only 56.7 per cent, as compared with the 1950 average of 69.9 per cent.

Chicago—Southwest

All the sludge floated within 24 hr., but it was very sensitive to vibration and movement and after 72 hr. some of the sludge had settled to the bottom. At the end of 120 hr. more sludge had settled to the bottom, but most of it was floating. Undoubtedly some activated sludge was present, causing that portion of the sludge to drop to the bottom, as the operator at the plant stated that some activated sludge was mixed with the primary sludge as the result of the overflow from the waste activated sludge concentration tanks returned to the influent of the primary tanks.

Detroit

All of the sludge had floated at the end of 24 hr. and remained that way for the first 48 hr., but at the end of 72 hr. 80 per cent of the sludge was on the bottom and at the end of 120 hr. all of the sludge was on the bottom. Digested sludge was present, as the raw sludge had a volatile content of only 54.6 per cent, in contrast to the average of 64.5 per cent volatiles in the raw

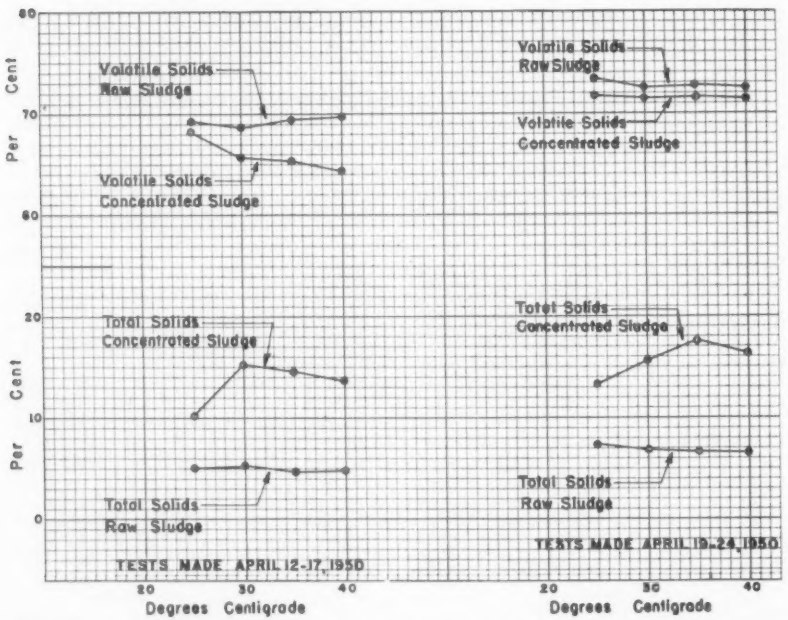

FIGURE 1.—5-day sludge concentration (Uniontown, Pa., primary sludge concentrated in 2-gal. jars) at various temperatures.

sludge according to the Detroit 1950 report. Digested sludge no doubt was being returned to the primary tanks for concentration and mixing preliminary to vacuum dewatering. The subnatant was of a tan color.

Cleveland—Easterly

All of the sludge was floating after 24 hr. and stayed in that condition for the entire 120-hr. period. The subnatant was yellow-green.

Cleveland—Southerly

The sludge, which originated in Imhoff tanks, rose slowly and at the end of 72 hr. there remained 1 in. of sludge on the bottom. At the end of 120 hr. all of the sludge was on the bottom and the liquor was black. It is obvious, from the low volatile solids content and the behavior of the sludge during concentration, that some digested sludge mixed with fresh sludge had been brought up by the operator from the sludge compartment of the Imhoff tank by means of a pitcher pump.

Cleveland—Easterly

This is a mixture of raw and activated sludge from the Easterly plant consisting of 20 per cent raw and 80 per cent activated sludge by volume. The mixture at the end of 96 hr. had 3 in. of sludge floating on top and 2 in. on the bottom. No further change was evident at the end of 8 days. The quantity of activated sludge was too great to completely float the mixture.

Buffalo

All of the sludge was floating at the end of 24 hr. The sludge continued to float and compress throughout the 120-hr. period. The liquor was clear and had a tan color.

Pilot Plant Studies

The pilot plant was built by Authority forces from plans prepared jointly by Metcalf & Eddy, consulting engineers, and the Authority staff. The general layout is shown in Figure 3. The plant is located on property of the Homestead Mill of the U. S. Steel Company. A 70-g.p.m. vertical pump was placed in a 35-ft. deep manhole near the end of a 96-in. combined outfall sewer serving the entire municipality of Homestead, which had a 1950 census population of 10,040. Therefore, a representative municipal sewage was available.

The pilot plant consists of a combination aerated grit and pre-aeration tank with 30-min. detention, a 2-hr. circular clarifier for primary sedimentation, weirs for flow measurement, 10 hexagonal concentration tanks 13 ft. high

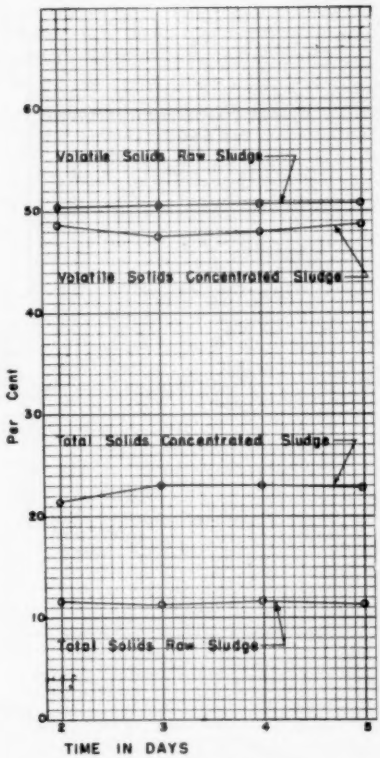

FIGURE 2.—Effect of time on concentration at 35° C. (Uniontown, Pa., primary sludge concentrated in 2-gal. jars).

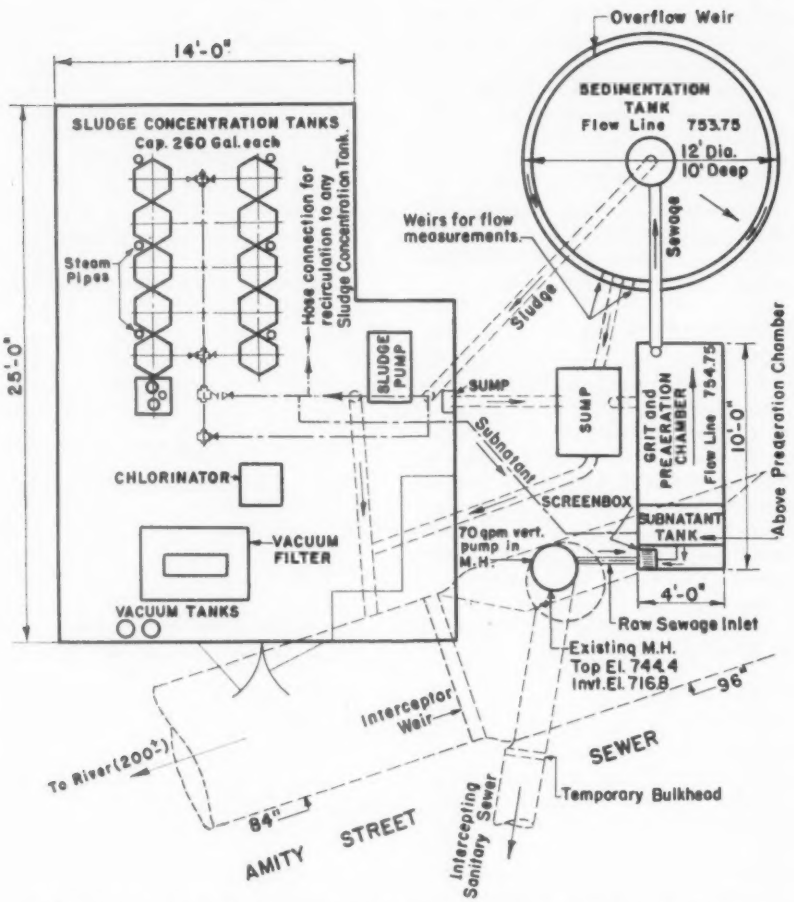

FIGURE 3.—Plan of Allegheny County Sanitary Authority pilot plant for sludge concentration studies.

with a sludge capacity of 260 gal. each, a sludge pump, and a chlorinator. Equipment was provided in the plant for field determinations of dissolved oxygen, pH, alkalinities, chlorine residuals, and settleable solids. Later, a 3-ft. diameter by 1-ft. vacuum string filter was furnished by Filtration Engineers, Inc., Newark, N. J., for dewatering experiments. The cost of the plant to date has been $13,000. It was placed in operation in September, 1950, but tuning up the plant and breaking in operating personnel required some time before operating data were made available.

The chief reason for the installation of the pilot plant was to demonstrate the practicability of concentration of sludge by biological flotation with the aid only of temperature and time controls. Although samples for suspended solids and B.O.D. removals through the plant were composited daily, this work

was considered to be secondary to the concentration of sludge. Detention periods were tested by means of chlorides and dyes on several occasions. Grit removals and the effect of pre-aeration were also observed. Daily dewatering experiments were made with the pilot filter for a period of a month. Prechlorination was started September 11, 1951. Tests of pumping equipment for transporting concentrated sludge through 195 ft. of 4-in. pipeline, with 8 right-angle bends included, were conducted on several occasions with success. The return of subnatant liquors to the influent was begun July 6, 1951, by means of an equalizing tank to observe the effect on the plant effluent and concentration of sludge. So far, no apparent or measurable influence has been observed.

Concentration Studies

Table III is an example of the analytical results of the concentration of raw sludge at temperatures ranging from 34° to 39° C. and for periods ranging from 24 to 144 hr. Under proper controls, volatile solids and pH decrease with time and alkalinities and concentrations increase with time. Concentrations increase with time up to a point, but after that methane digestion sets in and then the concentrated sludge begins to settle. It would appear that there is some relation between the observation that 120 hr. of concentration produces the most economical result and the findings of Heukelekian and Kaplovsky (15), who observed that the gas production curve dipped to its lowest point at the end of four days of digestion at 40° C. and then began to rise again 24 hr. later to its highest point, which was reached seven days later.

The 120-hr. concentration series of Table III has been divided into three parts—one representing the earliest period of operation, another a period of highest percentages of concentration, which occurred March 9 to May 14, 1951. The third period extends from May 15 to September 8, 1951. The March–May period is marked also by low solids content in the subnatant and

TABLE III.—Analyses of Sludge Concentrated in Pilot Plant

Conc. Time (hr.)	No. of Det.	Month (1951)	Sludge	Tot. Sol. (%)	Vol. Sol. (%)	Alk. (p.p.m.)	Temp.[1] (° C.)	pH
24	4	Jan.	Raw	3.6	70.1	425	34	6.3
			Conc.	8.7	70.7	750	39	6.1
48	4	Jan., Feb.	Raw	5.6	67.0	260	36	6.2
			Conc.	16.2	69.4	966	35	5.8
72	13	Jan., Feb.	Raw	4.1	74.6	555	35	6.2
			Conc.	16.7	75.2	1,218	38	5.7
96	27	Dec.,[2] Jan., Feb., Mar.	Raw	3.5	76.6	509	35	6.2
			Conc.	19.0	76.0	1,909	36	5.5
120	195	Jan. to Sept.	Raw	4.0	71.6	845	35	5.8
			Conc.	19.6	70.0	2,301	37	5.4
	20	Jan. 1 to Mar. 8	Raw	3.4	70.2	481	34	6.3
			Conc.	17.6	70.5	1,452	36	5.6
	59	Mar. 9 to May 14	Raw	3.4	72.1	—[3]	34	5.8
			Conc.	21.4	71.3	—[3]	36	5.1
	116	May 15 to Sept. 9	Raw	4.4	71.7	922	36	5.8
			Conc.	19.1	69.8	2,416	37	5.5
144	2	Feb., Mar.	Raw	4.0	67.5	—[3]	37	6.4
			Conc.	22.0	51.6	—[3]	35	5.3

[1] Raw sludge preheated.
[2] 1950.
[3] Test suspended.

somewhat higher results during the May–September period, Table IV. The explanation for the latter condition may be that the hot summer months caused initial digestion to begin in the sludge stored in the primary sedimentation tank. This is confirmed by the occasional appearance of floating sludge in the primary tanks during the hot months. It should be pointed out that, in spite of numerous experiments made with respect to sludge withdrawals, it was very difficult to obtain raw sludge with solids contents greater than 4 per cent and, therefore, a sludge blanket had to be maintained in the clarifier in order that a reasonable solids content could be withdrawn to the concentration tanks. The initial raw sludge during the period of highest concentration from March to May 14 contained an average of 3.4 per cent solids, in contrast to the May 15–September 8 period, when the raw sludge contained an average of 4.4 per cent solids. This would seem to indicate that a greater sludge blanket was maintained in the clarifier during the latter period and that the raw sludge had begun to digest before discharge to the concentration tanks during the hot weather. All raw sludge was preheated to the desired temperature before discharge into a concentration tank.

It is to be noted that the pH of the concentrated sludge during the period June–September (Figure 4) in many instances was found to be greater after five days concentration than the pH of the raw sludge. This likewise would support the theory that some predigestion had occurred in the raw sludge in the primary clarifier. The difference in the average pH of the raw sludge and the concentrated sludge for the two periods represented in Figure 4 is 0.6 and 0.2, respectively. The average temperature of the concentrated sludge was 1.6° C. higher during the May–September period than the temperature for the March–May period. It is practically impossible to control the temperature in individual concentration tanks, such as are installed in the pilot plant, to an exact degree by steam heat applied externally, but this difficulty should not be experienced in a properly designed full-scale concentration tank.

Figure 5 shows the concentration of sludge in a number of cases in samples taken at 2-in. intervals of the vertical depth of the floating sludge column. The sludge was floated out of the concentration tanks and sliced off at 2-in. depths and then mixed or homogenized and sampled. It is believed that the effect of pushing the sludge out of the tank by flotation on a water column, which is necessary to obtain such samples, probably caused the subnatant to penetrate more deeply into the sludge column. Higher average concentrations would result in normal operation, where the subnatant is withdrawn and the concentrated sludge rests on the bottom and is allowed to drain.

Figure 6 indicates the hourly B.O.D. determinations of the raw sewage influent to the pilot plant for a 5-day period.

Difficulties developed on occasion with the sewage pump, which clogged and required cleaning in the spring of the year when the rains came and grit and stranded solids from the combined sewer became excessive. Operation of the pilot plant was thus interrupted sometimes for periods of days until flood waters receded and made it possible to enter the sewer to the spot where the pump was located. Only one stoppage in operation of the pilot plant occurred as the result of industrial wastes too difficult to handle. This happened on May 15 and required cleaning out of the sewer, pump, and all tanks. The waste consisted of thick black metallic sludge having a solids content of 25.5 per cent with a volatile content of 22.7 per cent. The waste sludge contained 20 per cent iron, 30 per cent silica, 6 per cent aluminum,

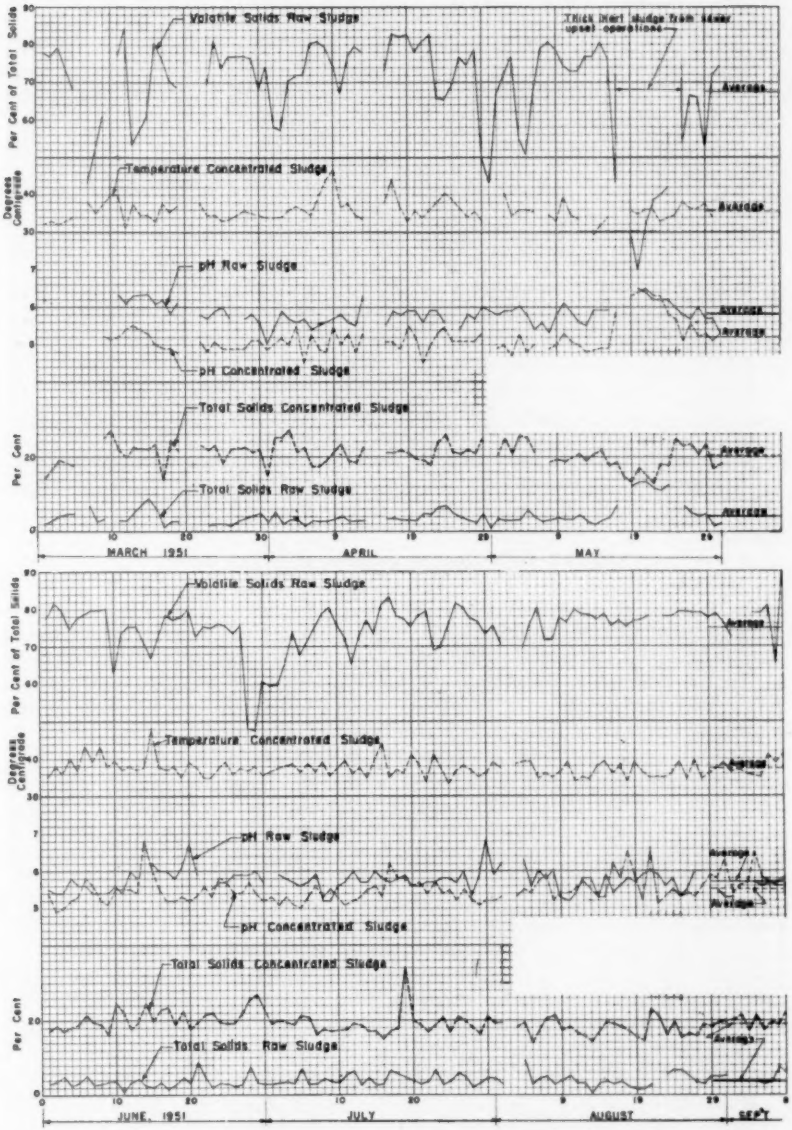

FIGURE 4.—Daily sludge concentration results for March–May period and for June–September 8 period.

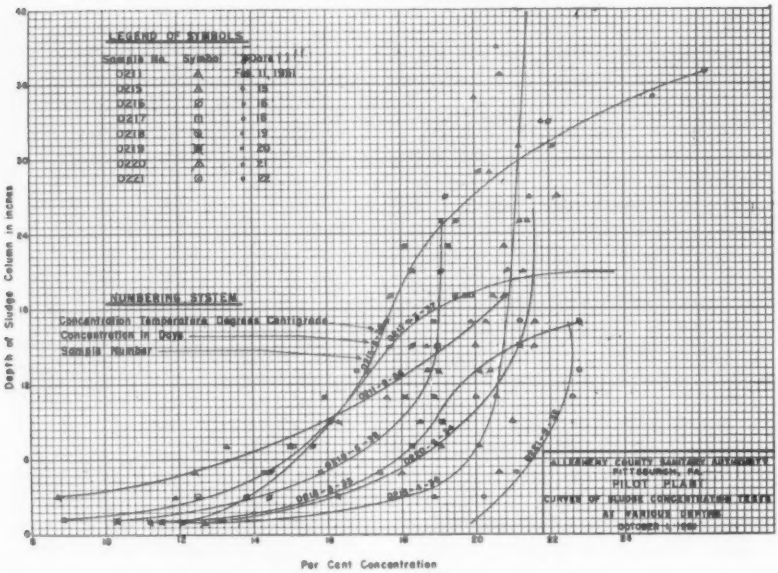

FIGURE 5.—Sludge concentration at various depths.

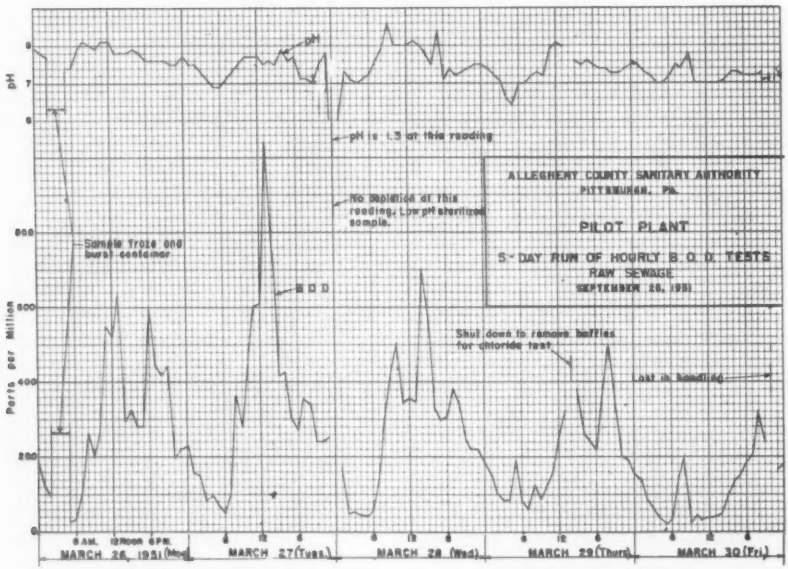

FIGURE 6.—Hourly B.O.D. results on raw sewage for 5-day period.

and 4.3 per cent sulfate, and, of course, could not be treated by any process. In a large treatment plant such wastes would probably be diluted to the point where their presence would not be objectionable.

During the month of September, 1951, concentrated sludge in the concentration tanks was sampled at the end of the first 48 hr. of concentration on 11 successive days with the following results:

Total solids, raw sludge	3.8%
Total solids, conc. sludge	14.6%
Volatile solids, raw sludge	77.0%
Volatile solids, conc. sludge	73.0%

Subnatant Liquors

Subnatant liquor withdrawn from the bottom of the concentration tanks was composited and analyzed and, more lately, discharged into an equalizing tank located on top of the pre-aeration tank, into which it was emptied at a uniform rate.

Figure 7 shows the analytical results of daily withdrawals of subnatant liquor. Table IV gives the average results for various periods of operation and time of concentration. The average B.O.D. of 2,970 p.p.m. for the 5-day concentration subnatants would increase the B.O.D. of the raw sewage of the Pittsburgh treatment plant less than 7 p.p.m. if the subnatant is returned to the incoming sewage, whereas the suspended solids would be increased less than 10 p.p.m. No evidence has so far developed to indicate that the return of the subnatant to the sewage influent is detrimental to the concentration process due to cumulative increase of subnatant solids.

On June 28, 1951, the raw sludge was found to possess an extremely low volatile content of 48 per cent and a high concentration of 7.5 per cent, which resulted in an unexpectedly high sludge concentration of 26 per cent and at the same time produced a subnatant containing more than 33,000 p.p.m. of suspended solids. This was the equivalent of a 3.3 per cent sludge. The cause of this condition could not be traced. Industrial wastes producing such a condition during the dry-weather flow of a community such as Homestead would be diluted in a large plant to a degree that should not be inhibitive to the sludge concentration process.

The average B.O.D.'s for the two periods (Mar., Apr., May and June, July, Aug.) illustrated by Figure 7 were practically the same as were the average volatile solids in the subnatant liquor, in spite of the marked difference in the average suspended solids content of the two periods, which has been discussed previously. The very hot weather experienced during these summer months would lend support to the theory that some predigestion was occurring to produce the high suspended solids content in the subnatant liquors.

TABLE IV.—Analyses of Subnatant Liquor from Sludge Concentration in Pilot Plant (Temp., 35° C.)

Conc. Time (hr.)	No. of Det.	Month (1951)	Susp. Sol. (p.p.m.)	pH	Alk. (p.p.m.)	B.O.D. (p.p.m.)	Vol. Susp. Sol. (%)
24	4	Jan.	2,400	6.0	290	1,016	68.8
48	4	Jan., Feb.	2,384	5.7	630	1,933	70.9
72	13	Jan., Feb.	3,214	5.6	756	2,190	74.3
96	27	Dec.,[1] Jan., Feb., Mar.	2,965	5.4	828	3,052	77.4
120	189	Jan. to Sept. 9	4,136	5.5	871	2,970	74.2
	17	Jan. 1 to Mar. 8	4,432	5.5	671	2,844	76.2
	59	Mar. 9 to May 14	948	5.3	778	2,732	76.0
	113	May 15 to Sept. 9	5,832	5.6	952	3,120	74.2
144	2	Feb., Mar.	555	5.3	1,060	3,775	82.4

[1] 1950.

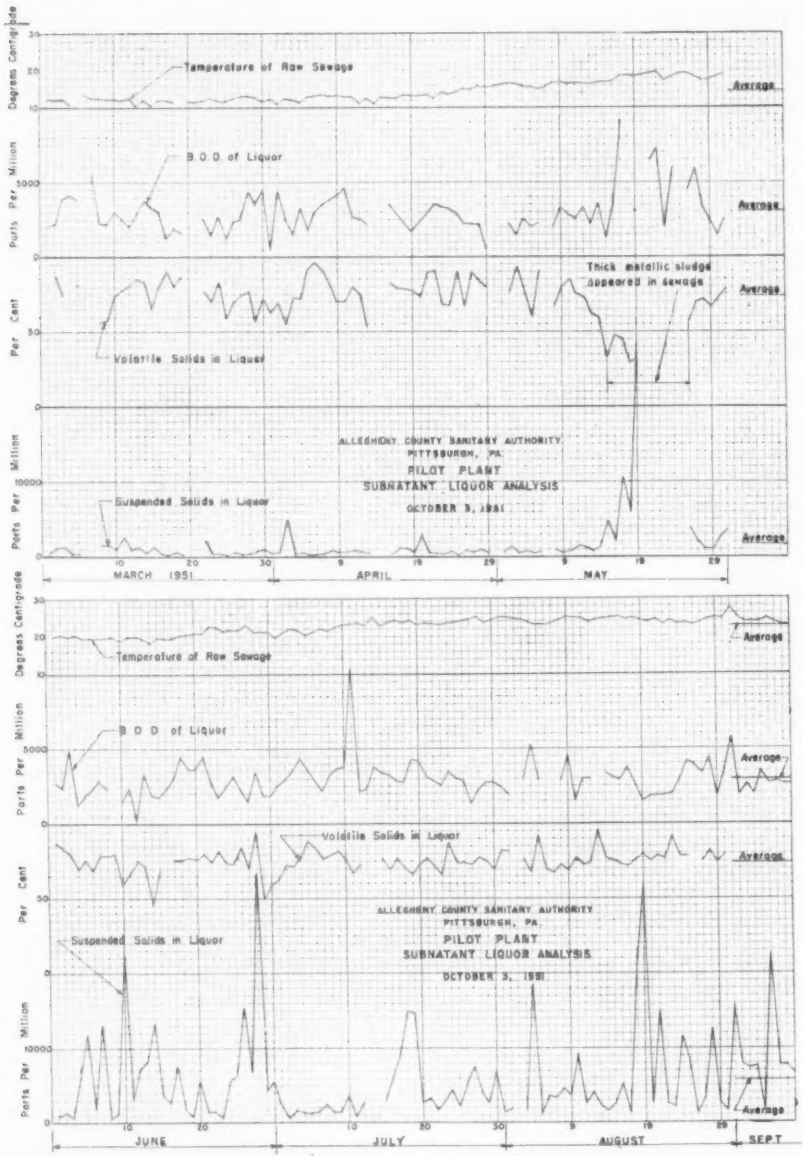

FIGURE 7.—Subnatant liquor analyses for March–May period and for June–September 8 period.

Suspended solids in subnatant liquors settled out readily in the equalization tank, thus requiring constant agitation for uniform feed.

Digestion of Concentrated Sludge

One of the concentration tanks and a 10-ft. section of 6-in. glass pipe were converted into digestion tanks to determine the digestibility of concentrated sludge. The tanks were partially filled with concentrated sludge, to which was added 10 gal. of digested sludge for seeding purposes. The mixture was permitted to digest for five days at 35° C. and then daily increments of concentrated sludge corresponding to 3 per cent of the digester volume were added. Additions of raw sludge were continued for 19 days with daily intermittent mixing by hand. The average volatile solids content of the initial concentrated sludge was 73.8 per cent and of the digested material at the end of 24 days, 44.8 per cent, indicating a well-digested sludge. Further experiments are proposed in this respect as soon as continuous mixing equipment is installed. It is believed necessary to mix the concentrated sludge with the digesting sludge for best results.

Gases were collected and analyzed throughout the digestion period. The quantity of gas collected was extremely low under the circumstances and would seem to confirm Keefer's (1) findings in this respect. Possibly part of the gases were trapped in the thick sludge.

Dewatering of Concentrated Sludge

Experimentation in the laboratory with Buechner and leaf filters indicated that concentrated sludge could be readily dewatered to approximately 30 per cent solids without the aid of conditioning chemicals. This was later confirmed in a series of tests on the daily production of concentrated sludge over a period of a month on a string filter supplied by the Filtration Engineers, Inc., of Newark, N. J. It developed that highly concentrated sludge could not be picked up by the vacuum filter. It would rise on the filter a few inches above the sludge level, then drop back. However, by diluting the concentrated sludge it was found that the filter picked up the sludge readily without affecting the normal rate of cake production and produced a cake which compared favorably with the cake produced in treatment plants where conditioning chemicals are used.

Pumping of Concentrated Sludge

Experience elsewhere indicated that difficulties would be experienced in finding equipment which would pump sludge concentrated to 20 per cent or more through pipelines leading to the incinerators. An extended search produced three types of units which it was thought might perform this service satisfactorily. The one which appeared to be the simplest as to type was the Moyno pump, manufactured by Robbins & Myers, Inc., of Springfield, Ohio. A unit of this type was installed at the pilot plant for experimental purposes. Gratifying results were obtained.

Summary

1. Studies made in the laboratory and later confirmed in pilot plant operation demonstrated that raw sludge can be concentrated biologically by flotation at an optimum temperature of 35° C. and that the most satisfactory results were obtained at the end of 120 hr. of concentration. No chemicals or admixtures were required. Best results are obtained by preheating the raw sludge to the desired temperature of concentration.

2. The subnatant from the concentration tanks, when returned to the influent raw sewage for treatment, did not present any treatment difficulties and did not increase the B.O.D. of the sewage more than 7 per cent and the suspended solids more than 10 per cent. No apparent effect was observed on concentration of the resulting cumula-

tive subnatant solids in the primary sludge.

3. Activated sludge by itself did not concentrate by biological flotation as did the raw sludge. Some mixtures of raw and activated sludge responded completely to flotation, but the activated sludge settled back to the bottom of the container in time. More experimental work on concentration by biological flotation with temperature and time controls of such mixtures might be warranted.

4. Aside from time and temperature controls the chief factors in the concentration of raw sludge appear to be volatile content and pH. Usually these factors are present in sewage in such favorable degree as to permit successful concentration of raw sludge by flotation.

5. In general, the higher the solids content of the raw sludge, the higher will be the solids content of the concentrated sludge. But there is no uniform pattern to be found in this regard. Evidently there is a solids limit to which raw sludge may be concentrated. Furthermore, other factors, such as volatile content, pH, and the condition of the raw sludge, influence the degree of concentration, assuming the same temperature and time controls.

6. The degree to which raw sludge having a solids content of 3.5 to 4.5 per cent can be concentrated as demonstrated herein, precludes the necessity for maintaining heavy sludge blankets in primary sedimentation tanks in order that a greater concentration of raw sludge is made available. This would reduce some of the difficulties of primary tank operation and produce a fresher sludge for best concentration results.

7. Inert matter, excepting unusually high concentrations of silt and grit, has no observable effect on the flotation process. The raw sludge moves up from the bottom of the tank as a column, either broken or solid, thus entraining all material within the moving column.

8. Volatile solids content and pH of the concentrated sludge are reduced with temperature and time, but alkalinities and concentrations increase under the same conditions.

9. Pre-chlorination to the extent of producing a residual has no measurable effect on the concentration by the flotation process according to the results of 20 days of operation with pre-chlorination.

10. Raw sludge concentrated by flotation can be dewatered on vacuum filters without the aid of conditioning chemicals, provided the concentrated sludge is diluted to a proper degree.

11. Concentrated sludge can be digested successfully, with resultant savings in construction and operating costs where digestion facilities are installed. A study of comparative costs and economics of sludge disposal including this concentration process was made by Laboon (16).

Acknowledgments

Laboratory work described herein was under the supervision of Gladys Swope, chief chemist, until late in 1948, at which time C. Fred Abel became chief chemist and took over the work.

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DISCUSSION

By Frank L. Flood

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Mr. Laboon's paper has summarized the development of a method for sludge concentration for raw primary sedimentation sludge under controlled conditions so as to produce a sludge with a moisture content averaging 80 to 82 per cent. This is an important development, as it adds a new tool for the use of the sanitary engineer. However, its use must be carefully weighed and evaluated by the profession in solving sludge disposal problems in the future.

Under controlled temperature conditions, in every instance where raw primary sludge alone was treated, the laboratory staff of the Authority has been able to concentrate the sludge from the sewage of large metropolitan areas to 18 to 20 per cent or more solids. In all the months of operation of the pilot plant on sludge collected from the Homestead sewage, the only failures to secure concentrated sludge by flotation were caused by local conditions, which could not possibly be duplicated in operations of the proposed Pittsburgh sewage treatment plant.

It should be noted that conditions in the Pittsburgh area are particularly suited to the use of this process and the incineration of concentrated raw sludge, because of the relatively low cost of fuel.

The possibility of incinerating liquid sewage sludge was early called to the attention of the profession by Schroepfer (1). He reported that when making studies of the type of sludge disposal to be used for the Minneapolis-St. Paul sewage treatment plant, in 1935, he concluded that if the moisture content and sludge could be reduced to 85 or 90 per cent, vacuum filtration could be economically dispensed with, assuming suitable equipment available for incinerating such sludge.

Incineration of concentrated raw sludge was inaugurated at the Ashland, Ohio, sewage treatment plant in 1941. The latest reported practice was to pump sludge daily from the primary sedimentation tanks to one of two concentration tanks, which were filled alternately. The concentration tanks were operated on the fill-and-draw method, supernatant being drawn off daily before the raw sludge was added. When a concentration tank was filled, it was permitted to rest from 3 to 10 days, depending on the progress of concentration, the needs for raw sludge storage capacity, and the operation of the incinerator units.

Under normal operations by the operators the moisture content of the concentrated sludge varied considerably,

although under skilled control during a test period sludge having an average of about 85 per cent moisture was obtained. The results of incineration of concentrated sludge in the multiple-hearth unit at Ashland during a test period have been given by Laboon (2).

Some information on the incineration of raw concentrated sludge during 1942 at the sewage treatment plant in Piqua, Ohio, has been supplied by Hufford (3). He reports the moisture content of the sludge entering the incinerator at 88 per cent. The plant as built provided for mechanical dewatering, but apparently this feature did not prove satisfactory because of an excessive proportion of industrial wastes. A method of direct incineration was developed for the liquid sludge in a small multiple-hearth incinerator.

The operations at Ashland and Piqua demonstrated that it was possible to incinerate liquid sludge containing 85 to 88 per cent moisture. However, the lack of assurance that the process of sludge concentration could be controlled so as to produce a sludge of fairly uniform moisture content within economical limits has delayed adoption of the process of liquid sludge incineration for other plants. Moreover, it could be demonstrated that concentration to a greater degree than that ordinarily obtained at Ashland and Piqua was desirable if direct incineration of liquid sludge was to be economical.

Preliminary studies for the Allegheny County Sanitary Authority on incineration of liquid sludge indicated that it would be economical to adopt this process at Pittsburgh if the sludge contained, on the average, 86 per cent moisture.

The subsequent operation of the pilot plant at Pittsburgh demonstrated satisfactorily that with a sludge heated to 95° F. and maintained at that temperature for five days, the raw liquid primary sludge would concentrate by flotation so as to contain on the average not more than 82 per cent moisture and possibly would average 80 per cent or less. Assuming an average moisture content of 82 per cent for the raw liquid sludge, the costs of three methods of sludge disposal for the Pittsburgh plant have been estimated as shown in Table I.

The project originally recommended for the Pittsburgh sewage treatment plant of the Allegheny County Sanitary Authority included sludge digestion, elutriation, mechanical dewatering, incineration, and power development in dual-fuel engines utilizing the digester gas. Under present conditions it is questionable whether it would be economical to develop power at the plant in competition with the local utility, when power can be purchased at less than 1¢ per kilowatt-hour. Accordingly, in the projects considered in Table I, an estimate has not been included for power development at the plant.

It should be noted that the sludge concentration and incineration project is estimated to cost about $1,350,000 less than the project involving digestion and mechanical dewatering, and $300,000 more than the project involving raw sludge dewatering. The estimated annual charges for sludge disposal of the project involving incineration of concentrated raw sludge are $100,000 less than for either of the other two projects considered.

The concentration of the raw sludge involves heating of the raw sludge and storage in heated tanks. Once concentrated, the sludge is in somewhat different form than material normally handled by sludge pumps and other sludge-handling equipment. Experiments at the pilot plant in Pittsburgh have demonstrated that the sludge can be pumped successfully by means of a Moyno pump and that it can be handled in screw conveyors. The sludge in this state has a foul odor, so that all tanks and means of conveyance for the sludge must have adequate provision to cap-

TABLE I.—Estimated Costs (in Dollars) of Sludge Disposal at Proposed Pittsburgh, Pa., Sewage Treatment Plant

Item	Project A[1]	Project B[2]	Project D[3]
Capital cost	5,283,000	3,939,000	3,646,000
Annual charges:			
Fixed charges, at 4.5%	237,735	177,255	164,070
Operating charges:			
Maintenance	41,840	36,750	50,000
Labor	120,960	105,500	145,500
Chemicals and filter supplies	80,000	—	114,400
Fuel	2,000	60,000	2,000
Power	17,300	17,300	23,700
Total operating charges	262,100	219,550	335,600
Total annual charges	499,835	396,805	499,670
Cost per ton dry solids for sludge disposal[4]	12.50	9.92	12.50

[1] Digestion, elutriation, mechanical dewatering, and incineration.
[2] Sludge concentration and incineration.
[3] Sludge dewatering and incineration.
[4] On basis of 40,000 tons per year.

ture the odors and to effectively destroy them.

The preliminary plans for the sludge disposal units at the Pittsburgh sewage treatment plant include heat exchangers for raising the temperature of the raw sludge to 95° F. (35° C.) before it is pumped to the concentration tank. It is proposed to provide eight sludge concentration tanks, each of sufficient capacity to hold a day's supply of raw sludge at a rate of sludge production equal to 150 per cent of the average design rate for 1970 conditions. Each tank has a capacity of 568,000 cu. ft. The tanks are rectangular in form, with three channels each 15 ft. wide, 105 ft. long, and 15 ft. deep. Three longitudinal collectors are proposed in each tank. After the sludge has concentrated, the subnatant liquor will be withdrawn and the longitudinal collectors operated to collect the sludge at one end of the tank. Screw conveyors are provided across the end of the tank to discharge the concentrated sludge to the inlets of the proposed pumps. Two sludge pumps are provided at each tank, arranged so as to operate singly or in parallel. The tanks are to be insulated and are to be maintained at the desired temperature by heating coils beneath the floor of the tank and by the introduction of warm air above the sludge level and under the tank roofs. The tanks are to be kept under a slight vacuum, with the air exhausted and discharged to the incinerators for use as combustion air.

The work at the pilot plant has shown that the subnatant liquor, which collects ordinarily within 24 hr. and practically without exception within 48 hr., has a relatively low B.O.D. and suspended solids content. It may, therefore, be advantageous to draw off much of this subnatant liquor soon after it accumulates and, thus, greatly reduce the effect of this subnatant return on the sedimentation tanks. This early withdrawal of subnatant will reduce the heating requirements for maintaining the concentration tank temperature at 37° C.

The studies for the sludge incinerators have not been completed.

However, the manufacturers of both multiple-hearth incinerators and flash driers have given assurance that it is practical to design equipment to handle the material. Preliminary studies indicate that the incineration plant would initially be of a size comparable with the multiple-hearth incinerator plant at the Detroit sewage treatment works.

The full possibilities of the use of this process in conjunction with sludge digestion remain to be explored. A detailed study has not been made of the economy of concentration of the sludge ahead of digestion tanks. Theoretically, it should be practical to relieve the overload on existing tanks and decrease the design allowances for new installations. It may be desirable to determine how concentrated a sludge can be digested, without providing extensive equipment inside the tanks to stir and mix the daily increments of raw with the digesting sludge, or to determine if suitable mechanical equipment can be provided to stir and mix sludge concentrations too thick for digestion without such mixing.

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FIRST QUARTER NPA CONSTRUCTION APPROVALS

The National Production Authority recently announced that 935 water and sewage construction projects with a total estimated value of $596,155,395 were approved for the first quarter of 1952 during the period from Oct. 31, 1951, through Jan. 15, 1952, and that allotments of controlled materials for this construction has been processed. Water facilities approvals accounted for $325,500,135 of the total, whereas sewage disposal approvals amounted to $270,655,260.

First-quarter allotments made by the Water Resources Division through January 18 totaled 139,409 tons of steel, 2,059,252 lb. of copper, and 142,168 lb. of aluminum. These quantities compare with corresponding available materials of 183,113 tons, 2,658,000 lb., and 175,000 lb., respectively.

Public reluctance to vote bond issues except in cases of proven necessity is a strong deterrent to unessential projects, according to the Division. In addition, review by the Division has pointed out possibilities of major conservation or substitutions for critical materials.

NEW YORK CITY'S OWLS HEAD POLLUTION CONTROL PROJECT *

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The Owls Head pollution control project, which will soon be completed, is the eighth major step in New York City's program to treat all of its sewage by 1959 under a comprehensive plan involving a total of 18 modern plants. Other projects now in various stages of completion are those at Rockaway in Queens, Hunts Point in The Bronx, and Port Richmond on Staten Island. Next on the agenda are the Bowery Bay Extension in Queens and the Oakwood Beach works on Staten Island, which will complete that part of the program designated to be undertaken by 1953. To what extent materials allotments and the lack thereof will retard progress remains to be seen.

The Owls Head plant is designed to treat 160 m.g.d. of sewage contributed by an ultimate population of 1,200,000 in the Bay Ridge, Bensonhurst, Boro Park, Prospect Park, and Flatbush sections of Brooklyn. Treatment will be by the high-rate activated sludge process. Sewage solids will be digested, the resulting gas utilized, and the residues discharged at sea.

The plant site is in the Bay Ridge section of Brooklyn on the waterfront north of the 69th Street ferry. It is adjacent to the Long Island R. R. yard on the north and the Owls Head park and the Belt Parkway on the east.

Novel Features

The project has a number of features that represent departures from previous design practice for New York City and some that are not found elsewhere. A few were introduced to best meet particular conditions, others follow a normal trend in the development of the art of sewage treatment, and still others spring from commitments made to a not altogether receptive public. Some of the distinguishing features are:

1. First plant in the United States designed exclusively for the high-rate activated sludge process. The design is based on the Department's experimental and development work. The process was originally called "modified sewage aeration."
2. First use in New York City of retractable (swing) air diffusers in aeration tanks and aerated channels.
3. Enclosure and ventilation of aeration and settling tank structures.
4. Ozonation of air in certain work areas and of exhaust gases from the ventilating system.
5. Prestressed circular concrete sludge digestion and sludge storage tanks.
6. Sealed, fixed roof digestion and sludge storage tanks.
7. Tanks built in pairs exclusively for two-stage digestion, with external recirculation and seeding of sludge at high rate, multiple separately controlled inlets in the primary tanks, and a radial baffle wall in each secondary tank.
8. Separate sludge gas storage in a low-pressure fabric-seal Wiggins gas holder. Although several holders of this type have been constructed, this

* Presented at a meeting of the Metropolitan Section, New York Sewage and Industrial Wastes Assn.; Brooklyn, N. Y.; Oct. 16, 1951.

is the first within the city limits. Only one, that at Los Angeles, Calif., has been built previously for the storage of sludge gas.

9. Facilities for disposal of grit at sea along with the digested sludge.

10. Ducking weirs for scum removal, the first to be built in New York City.

11. Scum tanks with mechanical stirrers.

12. A large Parshall flume for measuring plant effluent.

Importance of Plant

The Owls Head project represents a step of vital importance in the city's pollution control effort. The greater part of the present flow of 130 m.g.d. from the drainage area is discharged without any treatment whatsoever along the Bay Ridge shore line, resulting in extremely foul and unsanitary conditions. Gould (1) has stated:

"The tidal currents carry this filth into Gravesend Bay to such an extent that the waters here are unsafe for bathing and transport a part of the pollution to the end of the Coney Island beaches, creating a hazard to bathers at this popular resort and to a lesser degree at the south shore beaches of Staten Island. The cleaning up of this intolerable situation is considered one of the most important steps in the advancement of the program for clean waters."

It is expected that the type of treatment selected will remove about 80 per cent of the suspended matter and 75 per cent of the B.O.D., which should be adequate for this location and is substantially better than the minimum standards of the Interstate Sanitation Commission. As an additional safeguard, a contact channel is provided for possible future chlorination.

The area to be served by the plant, described above in general terms, consists of 13,765 acres (21.5 sq. mi.) extending along the Brooklyn shore from Coney Island Creek to the head of Gowanus Canal and as far inland as Eastern Parkway, Holy Cross Cemetery, and Ocean Avenue (see Figure 1). The region is largely residential in character, with some laundries and light industries.

At present, the sewage from this area is dumped into the Narrows and Upper Bay mainly at seven outlet points between 49th Street and 92nd Street.

History of Plant Design and Construction

The Metropolitan Sewerage Commission in 1914, the Board of Estimate in 1923, and the Department of Sanitation in 1931 all visualized the construction of three treatment plants along the Bay Ridge waterfront. Following studies on the economies of consolidation, the plan for one plant at the present location has appeared in all general plans for pollution control since 1937.

As definite steps for the construction of a plant were taken, opposition developed in 1940 from nearby residents. Although they endorsed the promotion of harbor cleanliness, they preferred to have the plant neighboring someone else's property. Actually, in the plans as finally developed, the distances from the plant structures and the outlet of the ventilation system to the nearest residence are more than 800 ft. and 1,700 ft., respectively.

Following the local objections to the site chosen, studies were made of six alternate sites as follows:

1. Owls Head.
2. Island in Upper Bay off 39th St.
3. 51st–58th Streets between 2nd and 3rd Aves.
4. Dyker Beach.
5. 36th–39th Streets west of 2nd Avenue.
6. Island in Gravesend Bay.

It was concluded that any other possible location would cost approximately $5,000,000 more than the present location.

FIGURE 1.—Map of New York City showing location of Owls Head sewage treatment plant and drainage area served.

In order to stem the tide of opposition, several commitments were made by way of giving maximum protection from any possible nuisance. Pursuant thereto, aeration and settling tank structures were enclosed, the digestion and sludge storage tanks were sealed, and a deodorizing system was installed.

Several local associations, including real estate groups, were originally numbered among the dissenters. After visiting some of the existing New York City plants and studying the problem for themselves, they became staunch supporters.

Although the covering, ventilation, and ozonation of the main tanks, which increased the construction cost of the project by more than $1,000,000, may not have been imperative, these features provide a margin of safety against possible complaint. At any rate, there is ample reason to believe that the people of Bay Ridge will be satisfied with their new neighbor.

It was the original intention to build a sedimentation plant with seasonal chemical precipitation. World War II delayed action and during the interval the modified form of the activated sludge process, called now "high-rate activated sludge," was developed (2)

(3) and proved so promising (4) that the original plan to use chemical precipitation was abandoned and the new aeration process adopted. Fortunately, in 1944, just at the time that this revision was in the offing, negotiations were started to acquire the property of the 66th Street power station of the Edison Company. Hence, it became possible to plan for the improved design in a location 260 ft. farther north than originally contemplated. This placed the plant that much farther from the residential area and adjacent to the Long Island R.R. yard, a compatible neighbor. Incidentally, it was possible to use much of the foundation of the power station.

Actual construction did not start until after the war, but suitable free fill was supplied and placed during the war, thus partially preparing the site. Fill came from local sources, from the Brooklyn-Battery Tunnel, and from Europe. The last named, constituting the major portion, came as ship ballast in the form of masonry debris, mine culm, and sand. Someone with a sense of the dramatic has said that the Owls Head plant is built upon the ruins of Coventry.

Three hulks of large wooden vessels had long blighted the waterfront in the area to be filled. Lack of immediate funds necessitated burying them in place. They proved to be stubborn corpses and finally compelled the driving of steel H-piles through them, after failure to penetrate with wooden piles, even with spudding.

Construction has proceeded fairly well on schedule in the light of the labor and materials procurement situations. It is believed that the works will be placed in operation early in 1952. Landscaping and roadways will follow at once.

Plant Units—General

The principal units of the project (Figures 2 and 3) are as follows:

1. North and south branch interceptors extending from 49th Street and 92nd Street, respectively, to the plant at 66th Street. The interceptors and the combined sewers which they serve are equipped with numerous automatic regulators, which will limit maximum storm flow, and with pontoon tide gates, which are designed to keep out sea water.

2. The pump and power house embraces the screening chamber, sewage pumps, dual-fuel supercharged engine-generator units, blowers, main electrical equipment, grit chamber, workshop, laboratory, office, and staff facilities. This main building is of a modernized classic-type design with high windows and deep reveals. The exterior features a fine white glazed iron spot brick with granite base and black terra-cotta trim. The interior features welded steel rigid frames, glazed structural facing tile, and quarry tile floors in several operating areas. Aymar Embury II, architect responsible for many pleasing parkway structures, was engaged to advise on the blending of the plant architecture with that of the adjacent park and parkways.

3. Enclosed in one major structure covering approximately 7 acres are six aeration tanks, eight sedimentation tanks, two scum stirring tanks, the return and excess sludge pumping equipment, the ozonation equipment and contact chamber, a chlorine contact channel for possible future use, and the Parshall effluent measuring flume. Enclosure panels are of cavity wall construction consisting of face-brick exterior and glazed structural facing tile interior. Natural lighting is provided by glass-block wall sections and roof vault lights.

4. Another major unit is comprised of eight sludge digestion tanks, two grit and sludge storage tanks, a gas holder, and sludge pumping units.

5. Docking facilities and a new sludge vessel provide for final disposal of grit and digested sludge at sea.

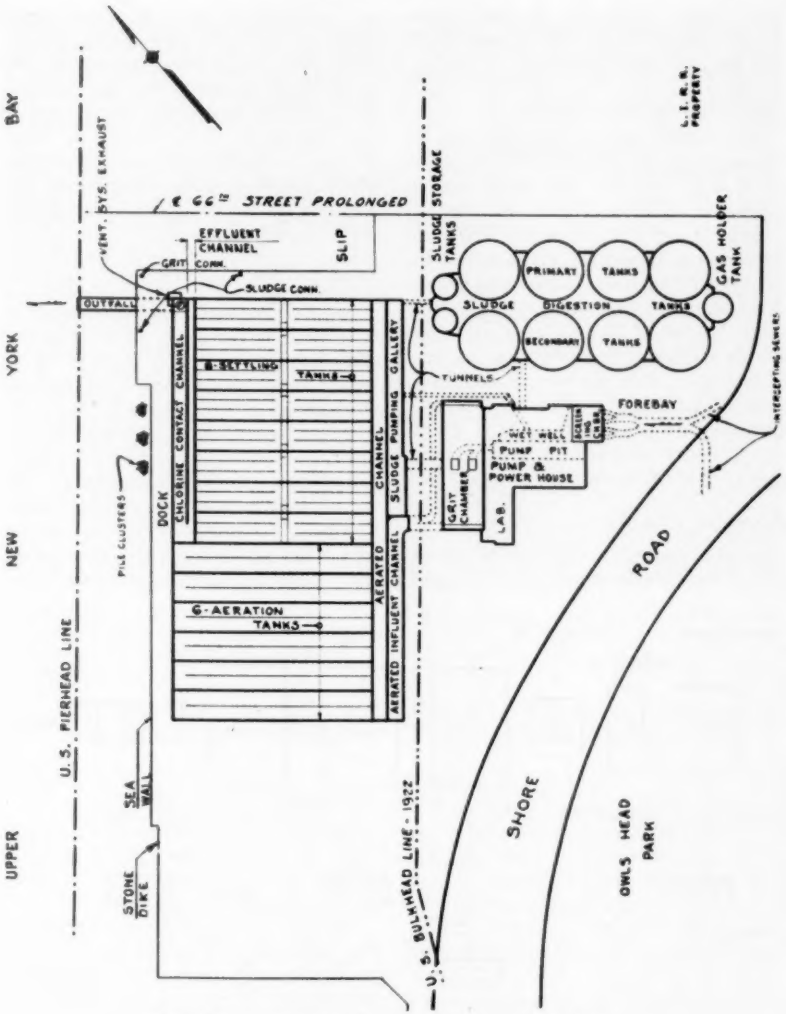

FIGURE 2.—Owls Head sewage treatment plant layout.

Basic Design Data

Population and Sewage Flows

As stated, the plant is designed to treat an average of 160 m.g.d. of sewage from an estimated ultimate population of 1,200,000 (133 g.p.c.d.) When the plant is first put into operation, a flow of approximately 130 m.g.d. is expected from more than 1,000,000 persons. Maximum flow in time of storm will be limited to twice the mean dry-weather flow, the excess being rejected to the harbor.

Sewage Characteristics

The assumed strength of the sewage, based on analyses, is: Suspended solids,

198 p.p.m. (0.22 dry lb. per capita daily); and B.O.D., 225 p.p.m. (0.25 dry lb. per capita daily).

Intercepting Sewer System

The north interceptor is 6 ft. in diameter at its start and enlarges to 12 ft. 6 in. by 8 ft. The south branch begins at 8 ft. by 8 ft. 6 in. and increases to 9 ft. square. The two branches merge at the plant into a 14-ft. by 8-ft. section, which runs to the screening chamber forebay. The seven main points of interception are 49th Street, 64th Street, Bay Ridge Avenue, 71st Street, 79th Street, 83rd Street, and 92nd Street. The two largest trunk sizes intercepted are 15-ft. diameter at 64th Street and 11-ft. equivalent diameter at 92nd Street.

Screening Chamber

In the screening chamber are four 6 ft. 9 in.-wide channels each equipped with a 66-in. by 84-in. hydraulic-pneumatic automatic sluice gate; a 3-in. trash rack, and a 1-in. bar screen, both of the back-raking type; and facilities for grinding screenings for return to the sewage, or for removal in cans. Velocity control is by means of critical-depth channels discharging to the wet well, which is enclosed and mechanically ventilated.

Main Sewage Pumps

Six main sewage pumps are designed to pump a maximum of 320 m.g.d. against a total dynamic head of 37 ft. with the largest unit out of service. One pump is of 55-m.g.d. capacity, variable speed, with 450-hp. motor; three are 60-m.g.d. constant-speed units with 500-hp. motors; and two are 85-m.g.d. variable-speed units with 700-hp. motors. The pumps are of the vertical type, have manual suction gate valves and motor-operated discharge gate

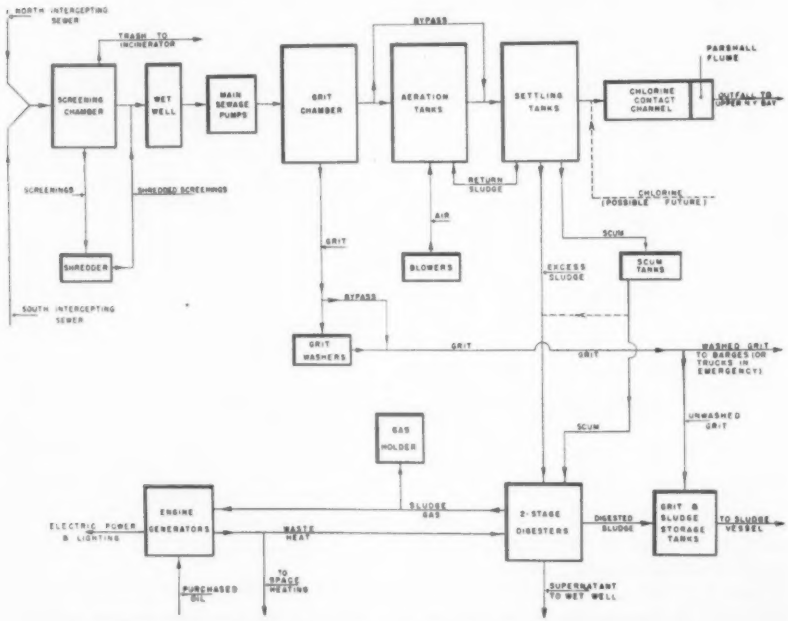

FIGURE 3.—Flow diagram of Owls Head pollution control project.

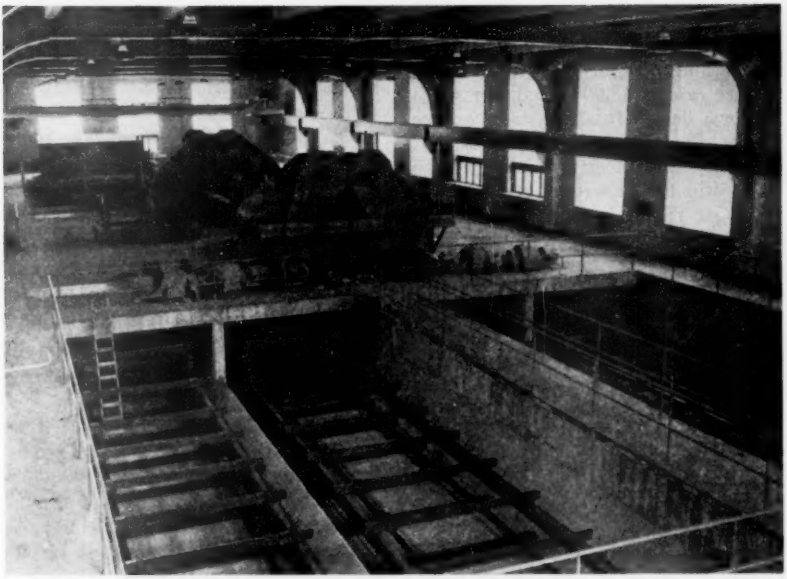

FIGURE 4.—Interior construction view of grit chamber. Grit is scraped to cross-collecting channels and thence to the raw grit elevators. Reciprocating grit washers and pneumatic ejectors are in the basement.

valves. A 90-in. diameter welded steel force main leads to the grit chamber.

Power Plant

Six 1,300-b.hp. dual-fuel supercharged engines are direct-connected to 900-kw. (1,125 kva.), 4,160-v., 3-phase, 60-cycle generators. Full voltage is used for the main sewage pump and blower motors, is transformed to 440 v. for principal auxiliary equipment, and is further transformed to 208/120 v. for lighting and small auxiliaries. Engine fuel will consist of sludge gas, plus diesel oil for ignition and supplementary purposes. Power requirements are estimated at 3,000 kw. for average design load and 4,000 kw. for maximum design load. Average gas production is expected to be 1.2 cu. ft. per capita daily, or a total of 1,440,000 cu. ft. daily. It is anticipated that 90 per cent of the power required will be derived from sludge gas. Waste heat from the engines will be utilized for sludge and space heating.

Blowers

Four 15,000-c.f.m. centrifugal blowers driven by variable-speed motors of 700 hp. will supply 0.40 cu. ft. of air per gallon of sewage with one unit out of service, and a maximum of 0.54 cu. ft. per gallon with all units in service. The rated blower capacity is based on a 7.75-p.s.i. discharge pressure, which represents a condition present only in the case of badly clogged air diffusers. This is a fortunate situation, as the margin of capacity under normal conditions will be available to meet possible increased air demand. The blower intake air will be cleaned by four 15,000-c.f.m. combined electrostatic and automatic self-cleaning filters. The blower discharge lines are equipped with cone check valves. The 42-in. diameter air main is of welded steel.

Grit Chamber

Four channels, each 28 ft. wide by 60 ft. long (Figure 4), allow for a surface rate of 48,000 g.p.d. per sq. ft. at storm flow with all units in service. Critical-depth discharge channels limit the maximum velocity to 1 ft. per sec. The estimated average grit removal is 3.5 cu. ft. per m.g. Equipment includes grit collectors, raw grit elevators, jig-type washers, pneumatic ejectors, four 96-in. by 60-in. motor-operated inlet gates, and four 72-in. by 36-in. manual outlet gates. The washers may be by-passed. Grit may be blown to the covered grit and sludge storage tanks, or to barges for final disposal at sea.

Aeration Tanks

There are six aeration tanks (Figure 5), each 347 ft. by 52 ft. by 14 ft. water depth. Two aerated channels approximately 25 ft. wide with an aggregate length of 1,080 ft. distribute the sewage to the aeration tanks and to the settling tanks. Each aerator is divided into two 25 ft. 6 in.-wide passes. Tanks and channels are curved in cross-section to assist spiraling of the flow. The tanks have a capacity of approximately 1,500,000 cu. ft. and the channels 380,000 cu. ft., or a total of 1,880,000 cu. ft. This represents a detention period of 1.9 hr. for average flow plus 10 per cent return sludge, or 2.1 hr. for average flow. The air is diffused through 6,950 ceramic tubes supported on retractable headers. There are six 60-in. diameter inlets and twelve 4-ft. by 4-ft. outlets. Sewage may by-pass the aeration tanks through two 7-ft. by 7-ft. gates connecting the aerated channels. The large aerated channels are calculated to give substantially equal distribution of flow to all tanks in service with gates wide open.

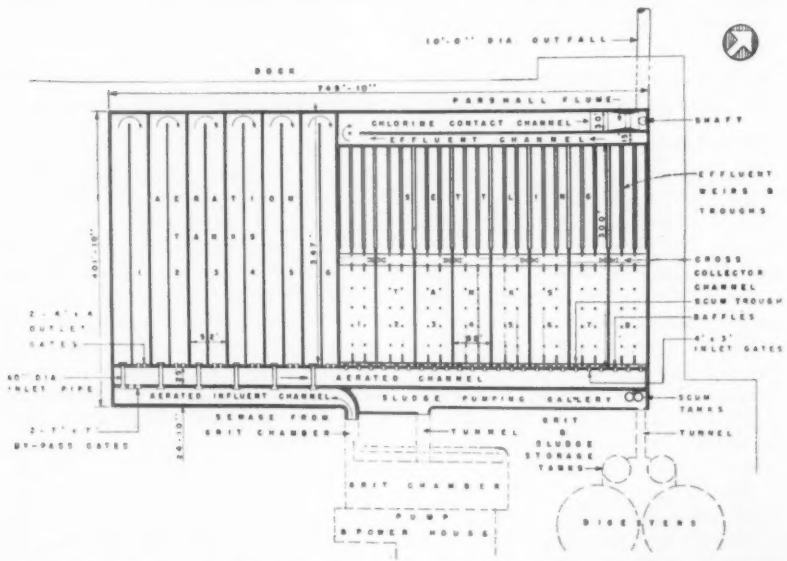

FIGURE 5.—Layout of aeration and settling tanks, chlorine contact channel (for possible future use), and large Parshall flume for (effluent) flow measurement. All units in heavy outline are housed in one ventilated structure with ozonation of air exhaust for control of any possible odors.

Settling Tanks

The settling tanks, eight in number, are designed for an overflow rate of 1,280 g.p.d. per sq. ft. Each tank is 300 ft. by 52 ft. by 12 ft. water depth, providing an aggregate volume of 1,500,000 cu. ft. This allows a detention of 1.7 hr. at average sewage flow and 1.5 hr. with 10 per cent return sludge.

There are three 4-ft. by 3-ft. inlet gates per tank. Effluent weirs are placed in a longitudinal direction beyond the middle of the tank and are equipped with saw-tooth weirs of aluminum. The cross-collector channel is at mid-length of the tank, much as in the Wards Island final tanks following recent structural changes (5). In a long tank, this design is considered best suited for dealing efficiently with density currents, whether arising from sludge blanket flow or salinity changes.

Scum is collected near the inlet end of the tanks, removed by ducking weirs, concentrated and emulsified in two stirring tanks, and then pumped to the digesters.

After passing through a chlorine contact channel (provided for possible future use), the plant effluent is measured by a Parshall flume, drops into a shaft, and is discharged through a 10-ft. diameter precast concrete outfall pipe in deep water at a point just inside the pierhead line. It is believed that the rapid currents at this point will produce good diffusion.

Sludge Digestion Tanks

There are four primary and four secondary digesters 103 ft. 4 in. in internal diameter with a water depth of about 36 ft. The total digester capacity is 2,400,000 cu. ft., or 2.0 cu. ft. per capita. The contents are heated by internal pipe coils. All digester units are insulated by an air space and facing brick, and by foam glass blocks laid on the concrete roof slab.

In operation, the digesters will be kept practically filled at all times; that is, the water level will be maintained within the range of the central lantern or circular collar on which sits the steel gas-collecting dome. Raw sludge is introduced through one of four inlets spaced around the circumference of the primary tank. A volume of raw sludge admitted to the primary digester causes an equal volume to be pushed hydraulically into the secondary digester through a pipe extending from the middle zone of the primary at its center to the secondary at the wall. The admittance of liquid to the secondary in turn causes an automatic overflow of supernatant liquor from one of three possible levels through an adjustable bell-mouth weir placed in an overflow box, which drains to the wet well. As precautionary measures, each tank has an independent emergency overflow and is equipped with liquid level indicators and alarm devices to protect the structure.

A special feature of the Owls Head two-stage digesters is the provision for recirculation and seeding of sludge at high rate by means of centrifugal pumps drawing from the center bottom of the primary tank and discharging back through the raw sludge inlets. To avoid short circuiting, the secondary digester is constructed with a radial baffle wall extending past the center of the tank (see Figure 6).

The prestressed design of digester tank walls was an alternate in the contract and was selected on the basis of competitive bidding. A 12-in. corewall was first poured. This was stressed in the vertical direction by high-strength steel wires set in grooves on the inside of the wall. The wires were machine stretched a predetermined amount before anchoring in place. Stressing in the horizontal direction was done by a machine which pulled a high-strength wire through a die as it was wound around the outside of the tank in helical fashion. All wires were then covered with pneumatically ejected mortar.

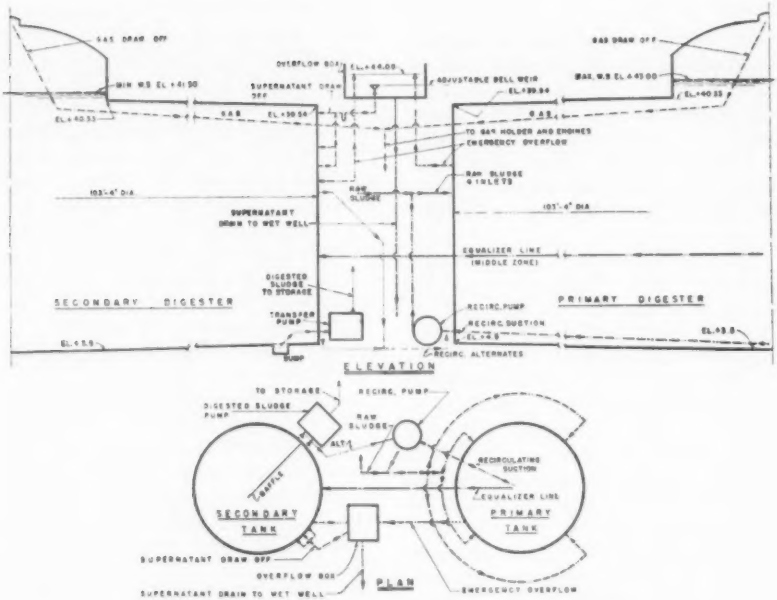

FIGURE 6.—Diagram of two-stage digester operation.

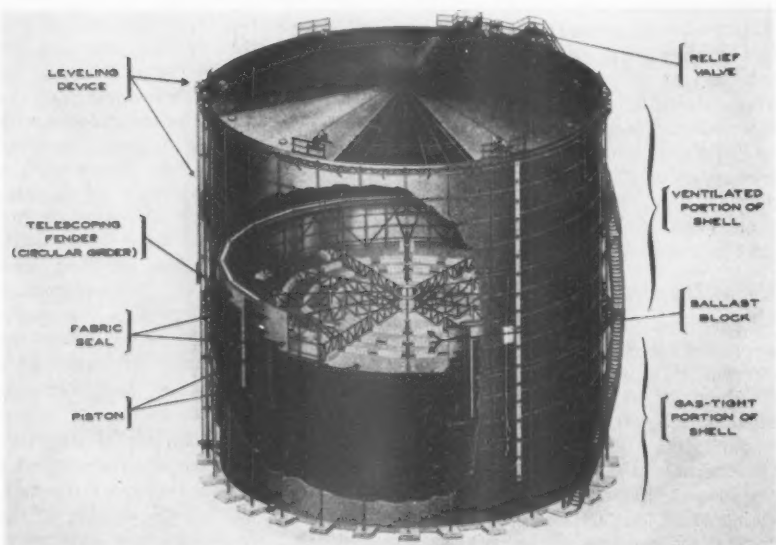

FIGURE 7.—Cutaway view of typical gas holder of type used at Owls Head sewage treatment plant.

Grit and Sludge Storage Tanks

The two grit and sludge storage tanks are 39 ft. 10 in. in diameter and have steep conical bottoms and domed roofs. Walls and domes are of prestressed concrete. The total storage capacity is 70,000 cu. ft. The tanks are elevated to allow gravity loading of the sludge vessel.

Gas Holder

A 100,000-cu. ft. gas holder, 51 ft. in diameter and approximately 65 ft. high, has been installed to save gas for daily peak loads. The holder is of the Wiggins fabric-seal type. The outer shell is fixed, the piston being attached to the shell by an ingenious system of fabric seals and telescoping fenders (Figure 7). The piston is ballasted with concrete blocks to produce a pressure of 10 to 11 in. of water.

Sludge Pumping Facilities

The sludge pumping units consist of the following:

1. In the gallery at the settling tanks—

8 triplex plunger excess sludge pumps rated at 300/150 g.p.m.; 6 are normal duty (115-ft. total dynamic head) and 2 are heavy duty (230-ft. total dynamic head).

8 centrifugal return sludge pumps rated at 2,300 g.p.m., with vari-speed drives. Assumed maximum rate of return is 12 per cent using 6 pumps.

2 duplex plunger scum pumps rated at 80/50 g.p.m.

2. In the digestion and storage gallery—

4 quadruplex plunger digested sludge transfer pumps rated at 400/200 g.p.m.

4 centrifugal digester recirculation pumps rated at 1,000 g.p.m. at 20-ft. total dynamic head. At normal lower heads one of these pumps can turn a primary digester over in 30 hr. or less.

1 triplex plunger sludge storage utility pump rated at 300 g.p.m.

Metering Facilities

The principal process meters at the plant are:

1—30-ft. by 20-ft. Parshall flume for plant effluent. Although there is a time lag between this meter and the main sewage pumps, it was a "natural" for this plant because of the presence of the 30-ft. wide chlorine contact channel.

1—42-in. diameter Venturi meter for blower air.

1—30-in. diameter Venturi meter for return sludge.

1—10-in. diameter Venturi meter for raw excess sludge.

1—8-in. diameter Venturi meter for digested sludge.

8—Venturi insert meters (4 at 8-in. diameter and 4 at 4-in. diameter) for sludge gas.

1—14 in. diameter orifice meter for total sludge gas utilized.

Ventilating and Deodorizing Equipment

There are 15 ventilating fans with a total capacity of 248,000 c.f.m. Three ozonators, each of 5-lb. per day capacity, can inject ozone into the intake air for the aeration and settling tank area and into the exhaust air going to an ozone contact chamber. The discharge tower for the ventilation system is located at the corner of the aeration and settling tank structure farthest from any residence.

New Sludge Vessel

The new sludge vessel will retain the general characteristics of the vessels in the existing fleet (6), except that it is of welded construction and has about one-third more cargo space. The boat has a 283-ft. over-all length, a 45-ft. beam, and a 12-ft. design draft. The total volume of the sludge compartments is 68,500 cu. ft. and the cargo deadweight capacity 1,900 long tons. Design for gravity unloading is achieved, as in the existing vessels, by

TABLE I.—Estimated Contract Cost, Owls Head Pollution Control Project

Contract No.	Title	Contractor	Cost
—	Rock spoil for sea wall	Gull and DeFelice	$ 48,500 (final)
1	South interceptor	Subterrane Corp.	2,140,000 (approx. final)
2	North interceptor	T. & T. Contracting Co.	1,700,000 (approx. final)
3	Bulkhead, landfill, and outfall	J. Rich Steers, Inc.	1,397,647 (final)
4	Pump and power house	Thompson-Starrett Co., Inc.	3,799,760 (approx. final)
5	Structures and equipment	Thompson-Starrett Co., Inc.	6,431,580 (bid)
6	Sewage pumps	Worthington Pump & Mach. Corp.	340,000 (bid)
7	Gas engine generators	National Supply Co.	646,208 (approx. final)
8	Blowers	Roots-Connersville Blower Corp.	277,492 (approx. final)
9	Heating and ventilating	Mechanical Installations, Inc.	187,471 (bid)
10	Plumbing	Joseph F. Egan	125,806 (approx. final)
11	Electrical equipment	Plymouth Electric Const. Co. Inc.	754,147 (approx. final)
12	Roads, drains and landscaping	Queens Structures Corp.	338,630 (bid)
13	Sludge vessel	John H. Mathis Co.	1,158,800 (bid)
	Project total		$19,346,041

placing buoyancy spaces beneath the sludge compartments so that the sludge level in the latter is always above the water line. Propulsion machinery consists of twin-screw direct-reversing diesel engines each of 700 b.hp. at 275 r.p.m.

Cost of Construction

The estimated construction contract cost of the project is $19,346,041, of which $1,158,800 is for the vessel, $3,840,000 for the interceptors, and $14,347,241 for the plant. Thus, the unit cost of the treatment plant proper will be approximately $90,000 per m.g.d. The contract breakdown is shown in Table I. The work was financed by the City of New York mainly from sewer rental funds.

Organization

The design and supervision of construction of the plant and the interceptors were done by personnel of the Department of Public Works, of which Frederick H. Zurmuhlen is Commissioner; Albert H. Morgan, Deputy Commissioner; and Richard H. Gould, Director of Sewage Disposal. During the design of the project Wellington Donaldson, Henry Liebman, and William A. O'Leary, successively, were Chief of the Design Bureau. Alfred Glock has been Chief of the Construction Bureau, with Leo Magid in charge of construction as Resident Engineer.

Philip L. Rhodes, Naval Architect, was retained to design the sludge vessel and supervise its construction.

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APPLICABILITY OF THE LETHAL PROPERTIES OF ULTRASOUND TO SANITARY ENGINEERING PRACTICE*

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The sanitary engineering profession has become increasingly aware of the application potentialities of ultrasonic vibrations during the past few years. In 1951 alone, three articles concerning the effects of ultrasound appeared in American sanitary engineering journals (1)(2)(3). The available literature concerning the applications of ultrasonic vibrations points the way to numerous possible uses for acoustic energy. There is much to be gained from studying the results that have been presented in the past and that will undoubtedly be presented in the future.

Sanitary engineers are principally concerned with what benefits, if any, will be available from the application of high-intensity, high-frequency sound waves to sanitary engineering processes. Will it be possible to coagulate suspended particles in water and sewage more rapidly? Will it be possible to sterilize water and sewage effluents with ultrasonic vibrations? Will it be possible to decrease the unit cost of treating sewage and industrial wastes? In order to determine the answers to these problems, it is necessary to examine the usual methods by which high-intensity acoustical energy may be applied to liquid media.

Common Ultrasonic Generators

At present there are two well-developed methods available for the conversion of electrical energy into high-intensity liquid-borne sound. The first method involves the utilization of the magnetostrictive properties of certain metals, especially nickel and annealed cobalt. When these metals are placed in an alternating magnetic field, the metal expands and contracts parallel to the direction of the magnetic field. By coordinating an electrical circuit to properties such as density, modulus of elasticity, and mass of the metal, it is possible to create a resonant magnetic field that will cause a rod to oscillate appreciably and generate sonic energy. The metal rod will generally tend to heat because of eddy currents and internal friction, so that the rod must be cooled in order to maintain constant operating conditions. Temperature changes, affecting the physical properties of the metal, detune the electrical circuit and decrease the energy output of the generator. In practice, the metal rods are usually made of laminated nickel sheets, which reduce the eddy current losses and diminish the heating effect. Although the linear displacement of the ends of the rod is limited by the modulus of elasticity (displacements greater than the limiting displacement rupturing the rod), bulk or volume displacements may be greatly increased by placing a metal diaphragm or piston on the end of the rod.

This type of generator has been used only in laboratory experimentation; plant-scale operation has not yet been successful. One of the major disadvantages to the use of high-intensity sound generated by magnetostriction

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generators is the low acoustic frequency at which the metal rod vibrates. Because of the limitations of the various physical factors indicated above, the frequency of magnetostriction generators is almost always within the audible range. This means that extensive preparations must be made to isolate the sound source, because the high intensity makes the sound unbearable. A pilot plant generator used some years ago to treat milk required a steel sound-deadening shell, which cost as much as the sonic generator.

The second important type of generator is the piezoelectric, or crystal generator. The principle of the operation of piezoelectric oscillators was described in an earlier issue of THIS JOURNAL (3) and will not be repeated here. The generator utilizes a crystal which exhibits the reverse piezoelectric effect. Heretofore, the active element was a quartz crystal, but more recently synthetic barium titanate ceramics have been used with great success. The naturally-occurring quartz crystal has several serious disadvantages, which severely limit the possibilities of its use in plant-scale operations.

The major disadvantage of quartz is the limitation to the total power that may be delivered by such a crystal. Although the quartz generators have been used extensively in experimental work, they are not suitable for extension to large-scale operations. Quartz crystals are cut from mother crystals, which are naturally limited in size. The probability of using two or more quartz crystals in combination, driving them from a single or from separate generators, is slight because of the inherent inequalities in naturally-occurring crystals that prevent proper electronic matching without expensive and complicated electrical networks.

A second disadvantage of quartz is the excessively high voltage required to drive the crystal. The characteristics of quartz are such that voltages of the order of 30,000 to 40,000 v. are required to obtain desired crystal responses. Although the current drawn, and consequently the power consumed, is relatively low, the high voltage is undesirable from the standpoint of safety.

Synthetic barium titanate ceramics were developed during World War II. The only reason that barium titanate has not yet surpassed quartz for research work is that quartz has been available for a longer time. Barium titanate ceramics have many advantages that make them possible sources of industrial ultrasound. Because the material is synthetic, the ceramics may be produced in a variety of sizes and shapes. The voltage required to drive barium titanate ceramics does not compare with that required for quartz, being less by approximately three orders of magnitude. Of greatest importance, however, is the fact that ceramics may be made up as mosaics, similar to tile mosaics, in which all of the active elements are properly tuned with respect to one another. Under this circumstance, the acoustic power available may attain the proper order of magnitude for industrial or plant-scale operation.

One disadvantage of barium titanate should be pointed out; namely, that ceramics have very poor heat characteristics and detune readily unless properly cooled. The use of mosaics with small active elements, which may be force-cooled on both faces, tends to overcome this disadvantage somewhat.

Although magnetostrictive and piezoelectric generators are the best known and most widely used acoustic sources for the production of liquid-borne sound, there are other methods available. Because many of the effects of liquid-borne sound are attributable to the phenomenon of cavitation, which is discussed later in this paper, any device that is capable of producing cavitation may serve as a substitute for an ultrasonic generator. Promising studies have been conducted using a liquid jet with a suitable deflector placed in front

FIGURE 1.—Cavitation "generator" for producing ultrasonic vibrations.

of the orifice, such as is shown in Figure 1. This device requires no moving parts and no electronic circuits. The source of the energy-producing cavitation is the liquid stream itself. If this type of "generator" can be developed successfully, the possibilities of plant-scale applications of acoustic energy will be greatly enhanced.

Theoretical Considerations

It was implied above that complex acoustic generators were used primarily to produce cavitation in liquid. Although this is not entirely true, there are only a few cases in which the observed effects of ultrasonic vibrations have not been attributed to cavitation.

How do ultrasonic vibrations produce cavitation? It is necessary to point out that the effects of ultrasonic vibrations are not generally attributable to the high acoustic frequency, but rather to the high sound intensity. High frequencies, in the range which has been classified as ultrasonic (above 18,000 cycles per second), are used because it is possible to increase the acoustic intensity far beyond that which is tolerable at audible levels without endangering the hearing mechanism. As such high-intensity sound is passed through water, the liquid experiences alternating tension and compression. When the acoustic intensity is sufficiently high, the tensile stress placed on the water becomes great enough to rupture the liquid near some weak point in its molecular structure, such as a gas bubble or a dust particle. Indeed, the acoustic pressure variations do not even have to place the liquid under tension; if the instantaneous pressure is decreased low enough, the vapor pressure of the dissolved gases and of the liquid itself is reached, and the liquid is disrupted by the formation of gas bubbles. As the alternating high- and low-pressure zones created by the sound wave occupy very small areas, the bubble formation may be considered as a localized boiling.

Because the liquid subjected to the sound wave experiences successive high- and low-pressure phases, the bubbles formed in the low-pressure, or tension zones are quickly collapsed as the following high-pressure zone is encountered. As the formation and collapse of the bubble occurs very rapidly, it is reasonable to assume that the bubble does not contain very much gaseous material when it collapses. Under this circumstance the implosion may be related to a typical water hammer, with localized liquid pressures reaching the order of hundreds of atmospheres. Many investigators believe that the high-intensity shock waves formed by the collapse of the cavitation bubbles are responsible for destructive effects of ultrasonic vibrations.

There is one further consideration that should be mentioned. When the desired ultrasonic effect is the destruction of microorganisms, it is important for the cavitation implosion to occur in the immediate vicinity of the bacterial cell. It has been estimated (4) that the effective range of a shock wave generated by the implosion is of the order of 1 or 2 microns. In order to kill bacteria, then, it is necessary that there be a cavitation nucleus in the molecular structure of the water surrounding the bacterial cell. The weaker this nucleus becomes, the greater is the chance that cavitation will occur, and the greater is the chance that the bacterial cell will be destroyed. Generally speaking, most of the effects indicated hereinafter may be explained by considering the influence of the variables on the molecular structure of the water-bacteria system.

TABLE I.—Per Cent of *E. coli* Surviving Ultrasonic Vibrations at Various Environmental Temperatures

Temp. (° F.)	Exposure Time (min.)							
	1	3	6	10	15	25	40	60
45	82.1	61.1	39.5	23.1	14.6	6.2	1.38	0.218
60	80.2	54.7	30.6	16.7	9.6	2.93	0.47	0.056
75	75.1	52.8	24.1	13.4	6.4	1.32	0.157	0.016
85	70.4	39.0	15.9	6.6	2.48	0.35	0.031	0.0029
98	62.5	32.4	10.1	3.0	0.75	0.056	0.0022	0.0000

Experimental Apparatus and Technique

The equipment used in these studies consisted mainly of a piezoelectric quartz generator operating at a frequency of approximately 400 kilocycles, as was described previously (1). In almost all of the studies the acoustic intensity was maintained at 5.7 watts per square centimeter. The method of measuring and controlling the acoustic intensity involved the calibration of a voltmeter across the crystal with a Siemens sound power meter as described in a previous article (5).

Unless otherwise indicated, the temperature of the bacterial suspension undergoing treatment was maintained constantly at 60° F. through the use of a thermally jacketed test cell.

The bacterial suspensions used in all of these tests, unless otherwise indicated, were made by suspending a portion of a 24-hr. nutrient broth culture of *E. coli* in sterile distilled water. Analytical results were obtained by withdrawing samples of the test suspension periodically and plating them on nutrient agar after suitable serial dilution. The culturing and analytical methods were described previously in greater detail (1).

In all cases, control suspensions were observed to eliminate undesirable environmental variables that might affect the test results.

Experimental Results

Temperature

The environmental temperature of the medium in which the bacterial cells are suspended plays a very important role in determining the rate at which they are destroyed. Table I and Figure 2 show the results of a series of experiments in which the environmental temperature was varied between 45° and 98° F.

The results indicate that increases in the environmental temperature always lead to increases in the rate of bacterial destruction within the temperature range explored. The highest temperature used in this study was the optimum growth temperature for *E. coli*, the bacterial species being investigated. Control suspensions of bacteria held at these same environmental temperatures showed no appreciable change in numbers within a time period of 1 hr.

If the results of Figure 2 are replotted using time and temperature as arguments and per cent kill as a parameter, the curves of Figure 3 result. This figure shows some very significant facts. If the curves of equal kill are extrapolated to the ordinate, they meet at a single point. This intersection occurs on the ordinate and the implication is that, at the temperature represented by the point of intersection—namely, 140° F.—practically instantaneous bacterial destruction should be attained. Furthermore, because the point represents various percentage

kills, it is reasonable to expect sterilization at this point also. Two special series of runs were made to test the validity of the hypothesis that when the environmental temperature was maintained in the vicinity of 140° F. practically instantaneous sterilization is obtained.

The results of these special series show that at 131° F. a kill of 99.96 per cent was obtained in 5 min.; at 140° F. a kill of 99.88 per cent was obtained within 2 min. Thus, the results tend to substantiate the prediction of the curves, that bacteria in an aqueous suspension are destroyed rapidly by ultrasound when the environmental temperature is approximately 140° F.

Surface Tension

The surface tension of an aqueous solution is a good indication of the intermolecular strength or weakness of the system as a whole. For this reason extensive observations were made to determine the effect of adding various

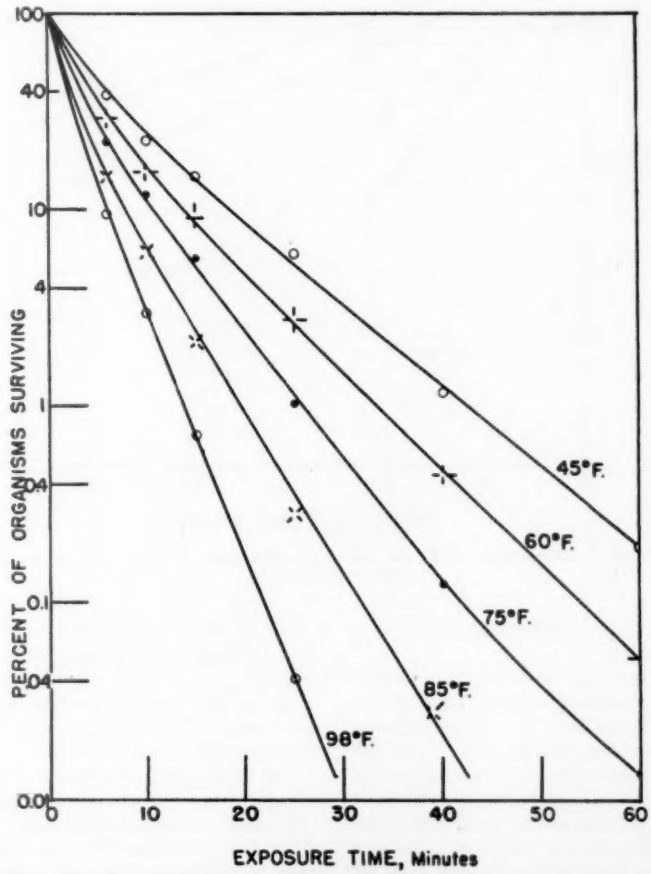

FIGURE 2.—Effect of environmental temperature on the ultrasonic death rate of *E. coli*.

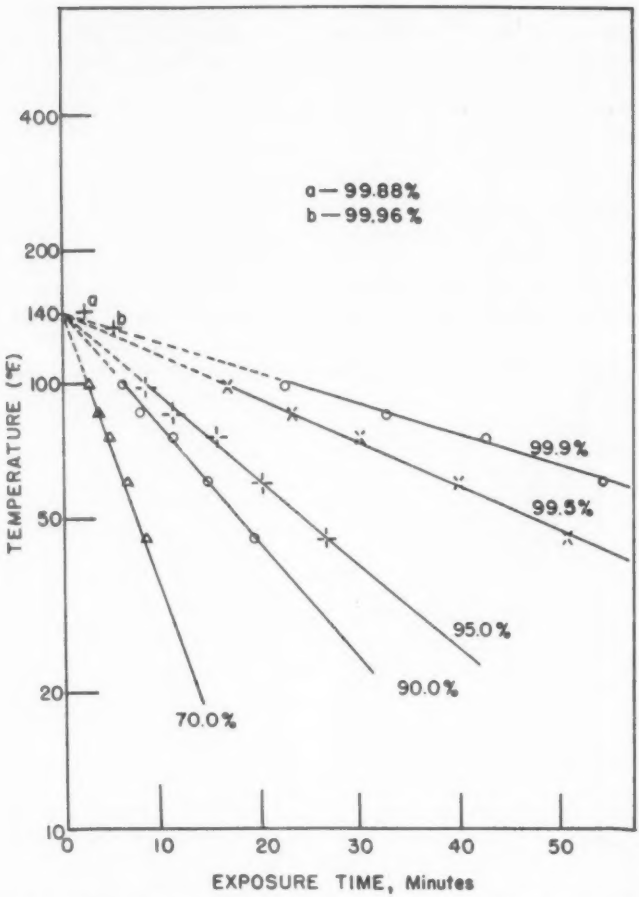

FIGURE 3.—Percentage of *E. coli* killed by ultrasonic vibrations at various times and temperatures.

nontoxic agents which altered the surface tension.

The chemicals used for this purpose included sodium chloride, sodium nitrate, sodium benzoate, leucine, glycine, Bacto-peptone, and gelatin. These substances were added in various concentration to the bacterial suspensions, the surface tension of the resultant system being measured by means of a du Nouy platinum ring torsion meter. Control suspensions, which were not sonorated, were observed in all cases, and whenever a significant change in bacterial numbers occurred because of the presence of the surface tension alterant, that suspension was eliminated from experimental consideration.

All of the test bacterial suspensions were sonorated for 40 min., the samples for analysis being withdrawn at appropriate intervals. The results were plotted and the killing rate determined. Whenever a varying killing rate was

encountered, the average rate exerted over the last 30 min. of the test run was used as the representative killing rate.

The correlation between the surface tension of the bacterial suspension and the rate of bacterial destruction in that suspension is presented in Table II and Figure 4. Figure 4 shows that the surface tension does have a significant effect on the ultrasonic killing rate of *E. coli*. As the surface tension increases, the killing rate increases likewise, the latter being an exponential function of the surface tension.

A statistical analysis of the data using a correlation technique shows that the estimating equation for the curve is

$$Y = -4.6 + 0.05X$$

where Y is the logarithm to the base 10 of the ultrasonic killing rate in reciprocal minutes and X is the surface tension in dynes per centimeter. The analysis showed that the coefficient of

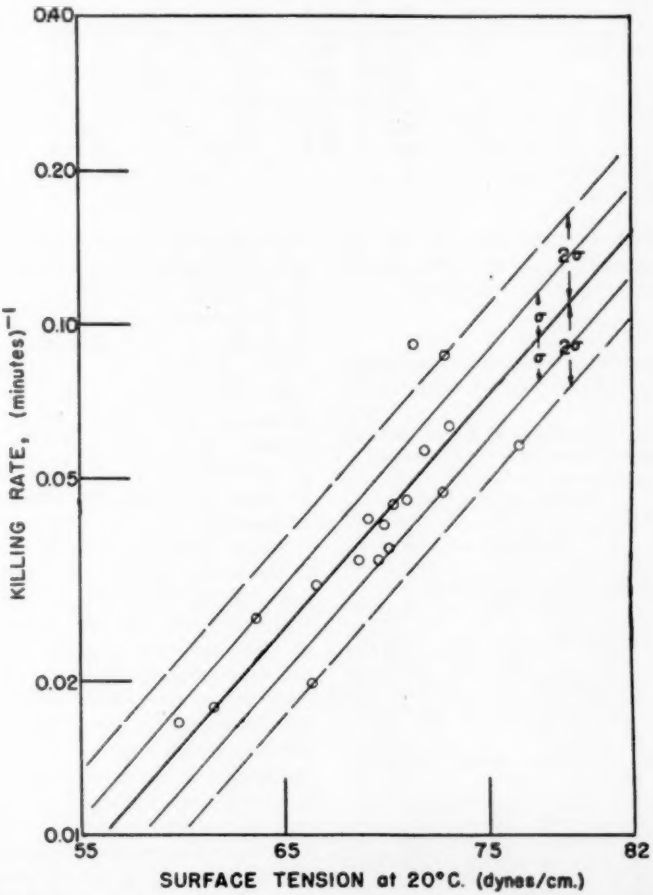

FIGURE 4.—Effect of surface tension on the ultrasonic death rate of *E. coli*.

TABLE II.—Percentage of *E. coli* Surviving Ultrasonic Vibrations in the Presence of Various Compounds Which Affect Surface Tension

Compound	Conc. (p.p.m.)	Exposure Time (min.)				Surface Tension[1] (dynes/cm.)	Killing Rate (min.$^{-1}$)
		6	15	25	40		
Distilled water	—	110.0	58.3	35.8	0.132	72.8	0.047
Sodium chloride	8,500	80.9	44.4	10.5	0.154	76.6	0.057
Sodium nitrate	200	67.0	28.5	3.72	0.91	73.1	0.063
	600	67.0	32.9	5.01	0.119	71.4	0.092
Sodium benzoate	400	93.8	43.6	8.58	0.026	69.9	0.041
	1,200	75.7	35.5	11.7	0.103	72.8	0.088
Leucine	200	90.5	50.2	23.1	5.79	69.6	0.035
	600	107.1	61.3	36.1	12.3	63.7	0.027
	1,000	128.2	81.0	52.6	25.8	66.4	0.020
Glycine	400	95.4	43.9	17.8	2.33	71.0	0.045
	1,200	98.5	47.3	16.3	2.94	70.4	0.044
	2,000	96.8	47.6	16.1	4.32	69.1	0.042
Peptone (Bacto)	25	71.8	30.2	6.2	1.18	71.8	0.056
	75	73.0	29.2	14.1	3.60	70.1	0.037
	125	68.2	31.2	14.8	4.23	68.7	0.035
Gelatin	200	132.6	93.8	61.5	14.9	66.6	0.031
	600	85.0	65.0	40.8	22.0	61.6	0.018
	1,000	125.3	88.4	59.6	32.5	59.8	0.017

[1] At 20° C.

correlation for these data is 0.82, indicating that a definite relationship exists between the two variables.

Turbidity

To determine whether or not turbidity is a limiting factor affecting the applicability of ultrasound as it affects the use of ultraviolet, experiments were conducted in which varying amounts of two different types of turbidity were added to the test suspension. In the first series, fullers' earth turbidity was used. The results of these tests are shown in Table IIIa and Figure 5. Figure 5 shows that, within the range of turbidity explored, there was apparently no significant effect on the killing rate.

TABLE III.—Percentage of *E. coli* Surviving Ultrasonic Vibrations in Turbid Samples

Turbidity (p.p.m.)	Exposure Time (min.)					
	3	6	15	25	40	60
(*a*) Fullers' Earth Turbidity						
20	74.6	55.2	25.6	15.9	7.48	2.34
30	75.0	66.9	27.2	14.9	6.85	2.17
50	75.8	57.1	25.2	12.6	4.69	1.66
150	80.0	61.9	31.0	19.2	8.96	2.56
500	77.9	61.5	35.6	20.8	8.87	2.59
(*b*) Boston Blue Clay (Kaolin) Turbidity						
0.0	—	102.7	72.6	35.3	4.77	—
0.7	—	80.2	58.2	29.2	5.24	—
7	—	88.3	60.0	36.4	5.52	—
70	—	79.9	47.8	25.3	3.33	—
700	—	80.4	55.1	34.9	9.93	—
7000	—	87.9	70.8	55.4	39.1	—

Boston blue clay (kaolin) was used in the second series, the results being presented in Table IIIb and Figure 6. Figure 6 shows that the kaolin turbidity, like the fullers' earth turbidity, had no significant effect on the ultrasonic killing rate within the range below 700 p.p.m. As the turbidity in the test suspensions approached 1 per cent, the amount of energy absorption in the suspension, as indicated by the increased cooling required to maintain a constant temperature, became excessive, and the killing rate decreased appreciably.

A comparison of Figures 5 and 6

indicates that the decrease in the killing rate as the turbidity approached 1 per cent probably commenced when the turbidity was as low as 50 p.p.m. However, at low turbidity concentrations, the decrease in the killing rate was slight. It is of some significance that the two different types of turbidity particles gave approximately the same result, indicating that the effect of turbidity is more a function of the number of particles rather than a function of the shape of the particles.

pH

The pH of the suspending medium often has a significant relationship to the effectiveness of germicidal agents. It is well known that chlorine is most effective at low pH values, its effectiveness decreasing with increasing pH. It was, therefore, desirable to ascertain whether the pH of the suspending medium plays an important part in the lethal effect produced by ultrasound.

A series of experiments was conducted in which the bacterial suspension was

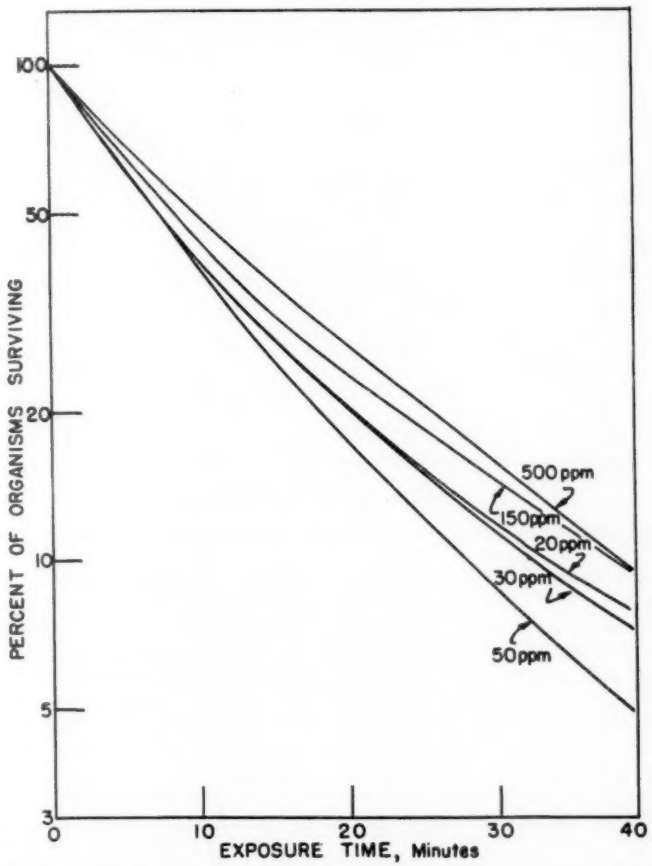

FIGURE 5.—Effect of fullers' earth turbidity on the ultrasonic death rate of *E. coli*.

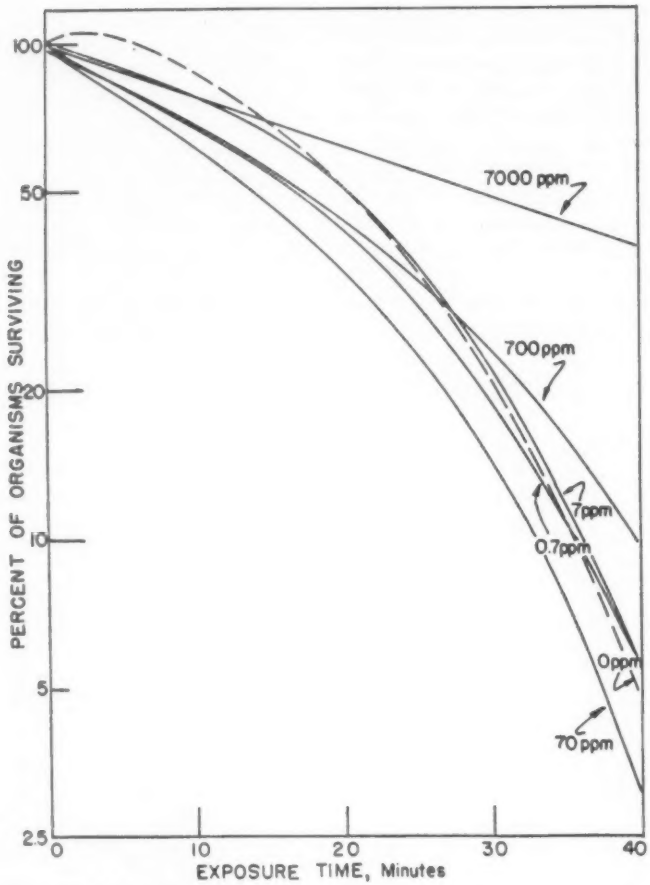

FIGURE 6.—Effect of kaolin turbidity on the ultrasonic death rate of *E. coli*.

buffered at various pH values ranging from 5.15 to 9.60. The organisms in the test suspensions were usually exposed to the effects of ultrasound for 40 min., although in some instances the exposure time was 2 hr. The dilution involved in plating test samples decreased the buffer concentrations used for pH control to such a point that the pH of the nutrient agar culture medium was not altered appreciably.

The buffer systems used for pH control were standard Clark and Lubs buffers. Control suspensions were made in each buffer solution, and the results showed that the buffers had no effect on the bacterial numbers during the time intervals involved. Even at pH 9.60 the change of bacterial numbers was within the limit of experimental error involved in sampling and plating.

The results of these experiments are presented in Table IV and Figure 7.

Figure 7 shows that during the first 20 min. of the test runs the pH of the sample did not seem to have an ap-

preciable effect on the killing rate. Even after 20 min. the samples buffered at 7.15 and below did not exhibit any significant difference in the killing rate. However, in the samples buffered at pH 8.10 and above, the killing rate did deviate from the initial rate, the rate increasing with longer exposure times.

To determine whether or not the killing rate would continue to increase over a longer time interval, two special series of experiments were conducted at the higher pH levels. In order to avoid complex killing rates, the suspensions buffered at pH 9.60 were not used when the interval of treatment was prolonged. The results of this series are presented in Table V and Figure 8. The short runs at pH 7.15 are included in Figure 8 for the purpose of comparison. It will be noted that the killing rates did increase continually over longer exposure periods. After sono-

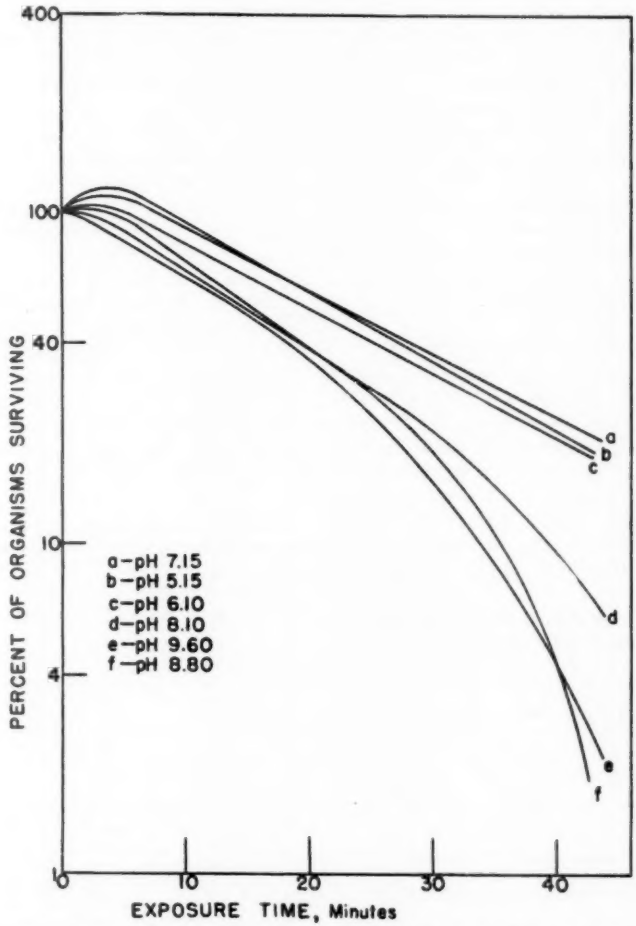

FIGURE 7.—Effect of pH on the ultrasonic death rate of *E. coli*.

TABLE IV.—Percentage of *E. coli* Surviving Ultrasonic Vibrations in Buffered Samples

pH	Exposure Time (min.)			
	6	15	25	40
5.15	108.2	75.6	48.2	20.8
6.10	99.4	61.4	42.7	20.4
7.15	109.2	70.3	44.1	26.1
8.10	85.9	49.4	30.9	9.55
8.80	92.5	52.9	29.0	4.48
9.60	78.7	53.2	23.7	4.55

rating suspensions at pH 8.80 for 70 min., the killing rate became almost instantaneous, that is, the slope of the curve was almost vertical.

As a result of these experiments, the conclusion may be drawn that the pH of the suspending medium does not influence the ultrasonic killing rate over short (less than 20-min.) time intervals. If the ultrasonic destruction of microorganisms is carried out over a longer time interval, the killing effect is greatest at the highest pH.

Effect on Endamoeba histolytica

It is well known that the cysts of *Endamoeba histolytica* are remarkably resistant to disinfection by chlorine, even in comparatively high concentrations. The potential danger resulting from such high chlorine resistance is obvious, and it was, therefore, of some importance to determine whether or not ultrasound could be used successfully against these forms of the *Endamoeba histolytica.*

Because of the nature of the organisms, the studies on the *Endamoeba* cysts were necessarily quite different from those on *E. coli.* The protozoan culture, obtained through the courtesy of Dr. S. L. Chang, Harvard University, was the NRS strain, which had been used extensively in research work. The culturing technic followed was similar to that of Chang (6)(7). The culture was normally carried on Boeck-Drbohlav egg medium, on which the organisms existed as active trophozoites. Three to 4 days before the subculture was used in the testing procedure, the organisms were transferred to the M/30 phosphate encystment medium recommended by Chang. At the time of testing the cysts were removed from culture tubes and centrifuged at 1,500 r.p.m. for 15 min. The sediment was suspended in sterile saline and placed aseptically in the test container.

Cyst enumeration was accomplished by removing a sample of the test suspension with a wide-mouthed pipette and placing a drop of the sample on a microscope slide. The cysts were stained with iodine and placed under a cover slip. The entire volume under the cover slip (1/25 ml.) was counted

TABLE V.—Percentage of *E. coli* Surviving Ultrasonic Vibrations in Buffered Samples, Long Exposure Series

Exposure Time (min.)	pH	
	8.10	8.80
15	55.9	50.6
25	32.5	21.1
40	12.9	5.06
55	—	0.72
60	3.40	—
70	—	0.0054
90	0.328	—
120	0.0225	—

TABLE VI.—Percentage of *Endamoeba histolytica* Cysts Surviving Ultrasonic Vibrations at 60° F.

Exposure Time (sec.)	Surviving (%)
1.5	42.0
5	34.4
10	15.6
15	8.34
30[1]	3.27
60[2]	0.00

[1] After sonoration, 1 sample was centrifuged, and the sediment was inoculated onto egg slants. Observations after 96-hr. incubation at 37° C. showed moderate growth.

[2] After sonoration, 2 samples were centrifuged, and the sediment was inoculated onto egg slants. After incubation as above, observations showed no growth in either case.

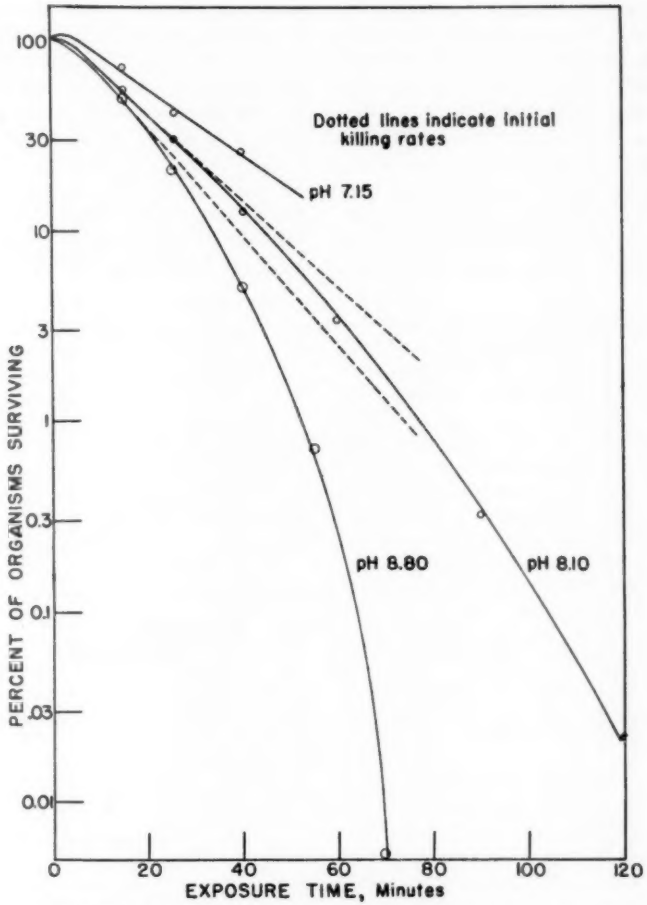

FIGURE 8.—Effect of pH on the ultrasonic death rate of *E. coli*.

under low-power (100×) magnification, approximately 225 fields per cover slip being observed. There was no difficulty in distinguishing between viable and destroyed cysts, as the latter were no longer discernible under the microscope, whereas the former were easily recognizable.

The results of the studies on *Endamoeba histolytica* are presented in Table VI and Figure 9, where the killing rate is compared with that of *Escherichia coli* and *Saccharomyces cerevisiae* as determined by Preston (8). Figure 9 shows that the cysts were destroyed much more rapidly than the bacteria or the yeast, the time required for sterilization being slightly over 30 sec. The active form of the protozoan, the trophozoite, was destroyed even more rapidly than the comparatively resistant encysted form.

Limitations of Ultrasound

There are several very important limitations to the application of ultra-

sonic energy as a bactericidal agent. These must be recognized before a proper evaluation can be made of the usefulness of this tool to the sanitary engineering profession.

In the discussion of the relation between high-intensity sound and cavitation, it was pointed out that the production of bubbles, or cavities, was essential to the destructive action. Unfortunately, these same cavitation bubbles also act to obstruct the passage of acoustic energy and, in effect, attenuate the sound wave. To reduce this attenuation it is necessary to apply the acoustic energy to thin liquid laminae in which the sound is not required to penetrate deeply. If this is not done, there may be a significant loss of acoustical energy. It can be demonstrated that under certain circumstances increases in the acoustic

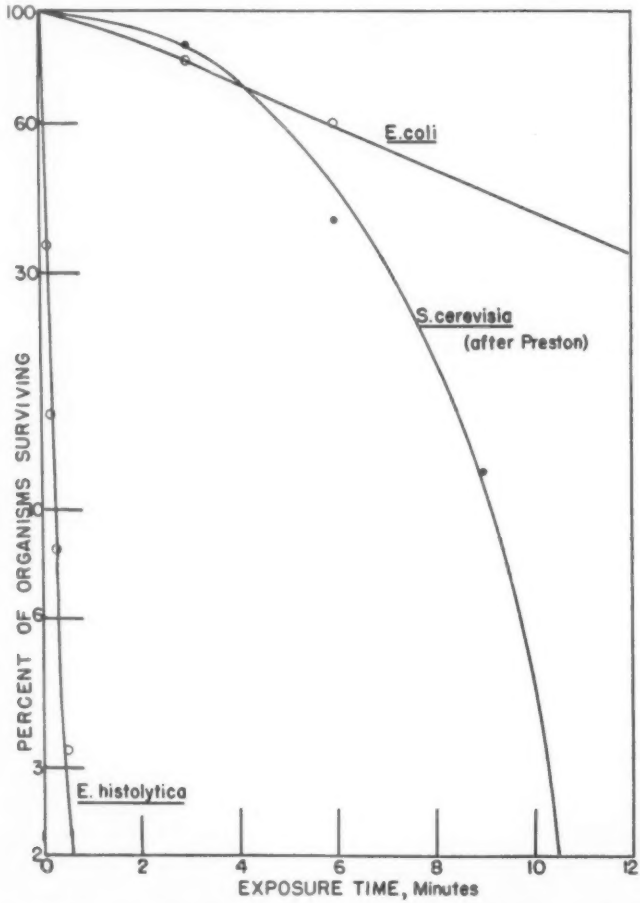

FIGURE 9.—Relative ultrasonic death rates of *Endamoeba histolytica*, *Saccharomyces cerevisiae*, and *Escherichia coli*.

energy may actually lead to decreased lethal effects because of excessive attenuation (4).

The disadvantage of treating large quantities of liquid in thin laminae is well known, so that bubble attenuation and the depth factor are significant limitations to the application of ultrasound to any liquid system.

When sewage or industrial waste is to be treated, two other complicating factors enter the picture. The detrimental effects of turbidity and surface tension on the ultrasonic killing rate have been previously described. Turbidity in domestic sewage or industrial waste is usually well above 500 p.p.m. Consequently, it is to be expected that there will be a considerable reduction in the lethal effect of the ultrasonic vibrations. Where the turbidity approaches 1 per cent, the effectiveness of ultrasonic energy as a germicidal agent will be severely restricted.

Generally speaking, the surface tension of water is reduced by the presence of most organic compounds, proteins having a very pronounced depressant effect. The few compounds that raise the surface tension do not increase it to a degree comparable to the depressant effect of proteins or other organic compounds. Consequently, the surface tension of domestic sewage or industrial waste will usually be significantly below that of pure water. Because the killing rate is directly affected by the surface tension, the bacteria in wastes encountered in practice will be affected less by ultrasound than those in aqueous suspensions used in laboratory work.

Conclusions

Based on present cost estimates, it would seem that ultrasonic vibrations are not practically applicable as a bactericidal agent. Using the data shown in Figure 3 and computing power costs on the basis of 2¢ per kilowatt-hour, it was concluded that operating costs would approximate $15,000 to sterilize 1,000,000 gal. of water if the temperature were already close to 140°F. It seems fairly certain, therefore, that the bactericidal properties of ultrasound will not be significant to the sanitary engineer.

Summary

1. Several types of ultrasonic generating equipment are briefly described. The most promising type seems to be the barium titanate piezoelectric generator.

2. The environmental temperature of the bacterial suspension is shown to have great importance in determining the ultrasonic killing rate. Extremely rapid killing was indicated in the neighborhood of 140° F.

3. Organic compounds such as proteins and other surface tension depressants have a protective action against the bactericidal effects of ultrasound. It is shown that the ultrasonic killing rate is an exponential function of the surface tension, decreasing with diminishing surface tension.

4. The turbidity of sewage and industrial waste limits the effectiveness of ultrasound as a bactericidal agent when the turbidity is greater than 500 p.p.m.

5. The pH of the liquid does not affect the killing rate significantly during short time (20-min.) exposures. For longer exposures the killing rate increases at higher pH levels.

6. Pathogenic protozoa, such as the cysts of *Endamoeba histolytica*, are rapidly destroyed by ultrasonic vibrations, the time required for sterilization being approximately 0.5 min.

7. Based on present cost considerations, the bactericidal properties of ultrasound do not seem to be practicable in the sanitary engineering field.

Acknowledgment

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SHOP-MADE RIGS EXPEDITE CLAY TUNNEL JOB

When progress on a 24,000-ft. sewer tunnel in Saginaw, Mich., was threatened recently by a shortage of clay miners, the contractor on the job designed two tunneling machines to help with the mining and completed the project four months ahead of schedule. The contractor was the Michigan Sewer Construction Company of Detroit and the machines were built completely in the company's own shop.

Fortunately, the path of the tunnel lay through a clay formation where a simple wheel-type machine would be practical. Producing such a machine for use in a tunnel with a bore of only 8 ft. 4 in. presented some difficult problems, but these were finally worked out successfully.

A small high-speed diesel engine previously purchased to repower a shovel was diverted to the sewer job and connected to a high-speed generator. Two four-spoke wheels with 3-in. cutter teeth on each spoke were fabricated with little difficulty. The cutter teeth were arranged so that they formed a solid cutting front when the wheel was turned.

A major problem was to obtain motors small enough to operate in the space available in the tunnel and yet powerful enough to start up the cutter wheels under full load, as the cutter teeth had to be imbedded constantly in the clay once the wheel was started. Another motor was needed on each machine to operate the conveyor belt, which moved the clay droppings back to waiting cars.

The machines were set to work in opposite headings in the tunnel, with the diesel-powered generator stationed on the surface near a centralized shaft opening. The tunnel advanced 1 to 3 in. at the turn of each wheel. Although progress was such that the cutters needed only one-third of the time required by hand diggers to mine an equal distance, it was impossible to utilize the full mining potential of the machines because the small bore of the tunnel allowed only a single-track railroad to transport the dug material back to the shaft. The job was accelerated, however, because highly skilled clay miners were not required to operate the machines and they could, therefore, be used steadily in addition to headings operated by ordinary hand methods.

The three-cylinder diesel engine used to drive the generator ran at a speed high enough to be direct-connected to the high-speed generator. This eliminated the need for a gear box and, of course, saved the company considerable time and expense in effecting the installation. Most of the machine parts went back to work on other equipment when the job was done.

Industrial Wastes

USE OF CALCIUM CHLORIDE IN THE TREATMENT OF INDUSTRIAL WASTES *

By Joseph A. McCarthy

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A few years ago a paper (1) was presented dealing with a method developed at the Lawrence Experiment Station for using calcium chloride and carbon dioxide in treating wastes resulting from the scouring of wool. Experimental data were presented at that time, including the results of a few large-scale experiments. The present paper sets forth the result of full-scale operations in New England plants and further experimental developments, not only in textile wastes, but in wastes from other industries as well.

Three wool scouring plants are now treating all their wastes with calcium chloride; none of them, however, is using carbon dioxide at present. The reasons for this will be discussed later.

Mill A

Mill A, an integrated plant carrying through completely the process from grease wool to yarn or cloth, has a plentiful supply of process water and uses more than 2 gal. of water per pound of wool scoured. This is somewhat above average as shown in earlier measurements. Synthetic detergents and soda ash, both in rather carefully controlled quantities, are used in the wool scour. The heavy scouring liquors and dilute waters from two rinsing bowls are combined for discharge. For more than a year this mill has been using calcium chloride in treatment of these combined wastes, with more or less rule-of-thumb control. Analysis of chlorides in the last set of composite samples taken from this plant indicated a dosage at the time of something less than 0.2 per cent of technical chloride, which was apparently somewhat of an overdose. The mill has convenient tanks with a rather ample settling capacity and the average sedimentation period after coagulating is at least 8 hr. At the time of the last sampling, the mixed wastes had a B.O.D. of only 1,800 p.p.m., of which 1,700 p.p.m. was in solution. After the calcium chloride treatment and sedimentation, the supernatant as discharged to the stream had a B.O.D. of 970 p.p.m., a reduction of 46 per cent from the original. It is apparent from these data that a considerable part of the dissolved B.O.D. had also been coagulated and removed. In reporting the original experiments, it was stated that removal of B.O.D. seemed limited to that in suspension, unless excessive doses of chloride were used. It seems from the results of the full-scale treatments that in large volumes considerable amounts of dissolved B.O.D. can also be taken out readily. Hexane solubles showed a 96 per cent reduction; about 98 per cent of the total suspended solids and 96 per cent of the volatile suspended solids were removed. The supernatant as dis-

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TABLE I.—Analytical Data for Wastes from Mill A

Sample	pH	Hexane Soluble (p.p.m.)	5-Day B.O.D. (p.p.m.)	Susp. Sol. (p.p.m.)	
				Total	Loss
Raw waste	8.4	1,700	1,800[1]	6,500	2,400
Supernatant	7.0	70	970	141	117
Removal (%)	—	96	46	98	95

[1] 1,700 p.p.m. in solution.

charged was remarkably stable and had a rather pleasant odor. The volume of sludge is something less than 10 per cent of that of the original waste. No attempt has been made thus far to recover the wool wax in this sludge. Analytical data for the samples are given in Table I.

Mill B

Mill B is a custom scouring plant generally treating medium or coarse wools. The mill has a rather limited water supply and this restricts the volume used in scouring to 1.5 gal. or less per pound of wool, thus tending toward the production of more concentrated wastes. Soda in generally rather high doses is always used and generally both soap and synthetic detergents are employed, with the relative proportion of each varying with the type of wool treated. This mill uses a four-bowl scouring train; all the heavy liquors from the first two bowls and that produced in the third bowl in the latter part of the day are discharged to the treatment plant. Lighter liquors from the third bowl and all the rinses from the fourth bowl may be discharged without treatment or returned to the process. All waste resulting from washing up of the bowls is also treated.

For more than three years this mill has been using calcium chloride controlled by occasional jar tests and by the appearance of the coagulating tanks. During the time that the last set of composite samples was collected, the dosage was about 0.25 per cent by weight of technical calcium chloride, which was again apparently an excessive amount of coagulant. The B.O.D. of the raw wastes as discharged to the treatment plant was 7,400 p.p.m., of which 4,600 p.p.m. was in solution and 2,800 p.p.m. in suspension. The supernatant, after calcium chloride treatment and approximately 5 hr. of sedimentation, had a B.O.D. of 2,000 p.p.m., a reduction of 73 per cent, and again an apparently considerable amount of the dissolved B.O.D., in this case about 56 per cent, had been coagulated and removed. Hexane solubles were reduced about 97 per cent and suspended solids nearly 99 per cent.

The mixture of treated scouring liquors, untreated rinse waters, and a small amount of condenser water, as discharged to the stream, had a B.O.D. of 270 p.p.m., hexane solubles of 100 p.p.m., and suspended solids of only 34 p.p.m. The color of the mixture was somewhat less than that of the receiving stream. Thus far, the company has pumped the sludge to a concentrating lagoon without any complaints in regard to odors. No attempt has been made by the company to recover the 8 to 10 per cent of wool grease in the concentrated sludge, but another concern has been experimenting with recovery. Analytical data for the latest samples are given in Table II.

TABLE II.—Analytical Data for Wastes from Mill B

Sample	pH	Hexane Soluble (p.p.m.)	5-Day B.O.D. (p.p.m.)	Susp. Sol. (p.p.m.)	
				Total	Loss
Raw waste	9.0	7,600	7,400[1]	6,400	5,600
Supernatant	7.8	240	2,000	68	58
Removal (%)	—	97	73	99	99
Mixed effluent	8.0	100	270	34	30

[1] 4,600 p.p.m. in solution.

Mill C

Mill C treats mainly fine wools, which produce wastes relatively high in grease and low in dirt. This plant segregates the heavy scouring liquors from the first two bowls of the four-bowl train and recovers the grease by super-centrifuging, removing from 25 to 45 per cent, and occasionally even more, of the available grease. The resulting liquor, as shown in the last set of composite samples, still contained about 0.5 per cent of hexane solubles and had 7,700 p.p.m. of suspended solids. The B.O.D. was 4,500 p.p.m., of which 2,700 p.p.m. (60 per cent) was in solution.

The mill has developed a rather novel process for treatment of this liquor; calcium chloride slurry is added and thoroughly mixed with the waste as fed to a low-speed centrifuge, from which the waste proceeds to a settling tank having a 2- to 3-hr. detention. Practically all of the sludge resulting from the coagulation rises to the top of the tank, from which it is removed by slowly revolving paddles, which sweep the material into a chute. The material thus removed, containing about 5 per cent solids, is discharged to a concentrating tank, which further increases the solid content to about 12 per cent.

The last sample of clarified liquor, with an indicated use of just less than 1.0 per cent of calcium chloride, showed a hexane soluble content of 90 p.p.m., a reduction of more than 98 per cent, and 320 p.p.m. of suspended solids, or 96 per cent removal. The B.O.D. was 1,480 p.p.m., which indicates that all the suspended B.O.D. had been removed and about 20 per cent of the dissolved B.O.D. as well. The liquor was remarkably stable and remained inoffensive after standing five days in the laboratory during the summer time. The sample of raw liquor developed nauseating odors overnight.

Thus far, only experimental recovery of grease from concentrated sludge has been attempted. In the laboratory, one sample of the sludge, which contained about 8 per cent solids and 3.5 per cent of grease, was boiled and centrifuged, with resulting recovery of about 0.7 per cent of wool wax of good color, or 20 per cent of the total available grease; also, 1.3 per cent of other hexane solubles. The addition of about 3.5 per cent of calcium chloride to the sludge following pH adjustment to 7.8 resulted in recovery of nearly 70 per cent of the hexane solubles in the sludge. The product of this experiment was slightly brownish in color, but it could have been further treated for recovery of low-colored wax.

At this same plant, in cooperation with Metcalf & Eddy, five successive experimental batches of strong waste, in each case about 800 gal. of waste, were treated with a dose of 0.85 per cent of technical calcium chloride, which was mixed into the liquors by carbon dioxide. For the five lots, the average reduction of hexane solubles was about 93 per cent; 70 per cent of the B.O.D. was removed; and the average supernatant had a suspended solids content of only 40 p.p.m., a reduction of 98 per cent.

As previously indicated, none of the plants has as yet included carbon dioxide in the treatment process. The Lawrence Experiment Station has conducted experiments from time to time with the wastes of all these plants, comparing the use of carbon dioxide with pH adjustment followed by calcium chloride with the calcium chloride now employed alone. In every case it has been found possible to reduce the amount of chloride required by 10 to 40 per cent. Apparently the mills are obtaining satisfactory results and are finding it relatively easy and cheap to use the chloride alone. Thus, they have not felt warranted in making the capital expenditures necessary for the introduction of carbon dioxide, even though all the plants have plenty of this gas available in their stacks. Table III gives analytical data for both

TABLE III.—Analytical Data for Wastes from Mill C

Sample	pH	Hexane Soluble (p.p.m.)	5-Day B.O.D. (p.p.m.)	Susp. Sol. (p.p.m.)	
				Total	Loss
(*a*) Full Scale; Degreased Heavy Wastes[1]					
Mixed wastes[2]	9.5	4,800	4,500[3]	7,700	3,700
Supernatant	8.3	90	1,480	320	260
Removal (%)	—	98	67	96	93
Sludge	—	24,000	13,300	46,000	30,000
(*b*) Joint Experimental Work; 800-Gal. Lots[4]					
Raw waste	—	5,200	6,000	2,040	—
Settled	—	390	1,790	40	36
Removal (%)	—	93	70	98	—

[1] Treated with calcium chloride and centrifuged.
[2] After degreasing.
[3] 1,800 p.p.m. in solution.
[4] Calcium chloride dosage of 0.85 per cent mixed with waste by carbon dioxide.

the full-scale and experimental treatments.

Mill D

Fairly large-scale experiments have been made on the degreased waste from mill D, which scours fine wools almost exclusively with relatively small volumes of water. Even after super-centrifuging to remove wool waxes, the wastes from this mill, which uses soap and a rather large amount of soda in its process, contained 13,800 p.p.m. of hexane solubles and 13,100 p.p.m. of B.O.D., of which about one-half was in suspension. Successive increasing amounts of calcium chloride without pH adjustment were added to portions of this waste. A supernatant resulting from 0.5 per cent chloride showed slight reductions in grease and B.O.D.; 1.5 per cent removed about one-third of the grease and one-fifth of the B.O.D.; 2 per cent gave a 95 per cent reduction in hexane solubles and removed all the suspended B.O.D., with a reduction of nearly 97 per cent in suspended solids. When 2.5 per cent of the chloride was added, 99 per cent of the grease was removed and the suspended solids remaining were only 8 p.p.m., as compared to 3,800 p.p.m. in the original waste. Analytical data for this waste are given in Table IV.

Mill E

Experimental treatment on a large scale has been carried on at Mill E, which will lead, it is hoped, to full-plant use. This plant uses a three-bowl train, scouring in the first two and rinsing in the third bowl. Medium-grade wools are generally scoured with a moderate amount of water, so that the wastes are rather high in suspended solids and B.O.D., but fairly low in grease. Scouring is carried out by the batch process; all three bowls are used more or less to saturation and then dumped at once. On one experimental lot sampled, a small amount of soap, larger amounts of synthetic detergent, and moderate amounts of soda had been used. With calcium chloride alone, it was found necessary to use 2 per cent to obtain a satisfactory "crack" with

TABLE IV.—Analytical Data for Waste from Mill D

Calcium Chloride (%)	Hexane Soluble		5-Day B.O.D.		Susp. Sol. (p.p.m.)		
	(p.p.m.)	Rem. (%)	(p.p.m.)	Rem. (%)	Total	Rem. (%)	Loss
0.0	13,800	—	13,100[1]	—	3,800	—	3,550
0.5	13,000	—	11,200	—	3,700	—	3,500
1.0	9,300	31	10,200	22	3,600	—	3,400
1.5	9,300	33	11,400	13	3,800	—	3,500
2.0	700	95	6,400	51	100	97	60
2.5	150	99	6,400	51	8	99+	4

[1] 6,600 p.p.m. in solution.

TABLE V.—Analytical Data for Waste from Mill E.

Sample	pH	Hexane Sol.		5-Day B.O.D.		Susp. Sol. (p.p.m.)		
		(p.p.m.)	Rem. (%)	(p.p.m.)	Rem. (%)	Total	Rem. (%)	Loss
(*a*) Mixed Scours and Rinse[1]								
Mixed wastes	9.0	5,300	—	7,800[2]	—	14,000	—	6,200
+2% $CaCl_2$	7.7	300	95	2,100	73	100	99	70
+1% $CaCl_2$ + CO_2	7.5	350	94	2,100	73	65	99	45
+1.2% $CaCl_2$	7.7	640	88	2,300	70	180	99	120
(*b*) All Synthetic Detergent								
Mixed waste	8.4	6,700	—	9,000	—	12,600	—	6,800
+2% $CaCl_2$, 150° F.	7.6	400	94	3,100	66	90	99	60
Two-step 0.4% $CaCl_2$, 100° F. +0.2% $CaCl_2$ + 0.02% lime	7.8	310	95	3,350	62	80	99	50

[1] Batch scouring.
[2] 3,600 p.p.m. in solution.

this waste. This resulted in removal of 73 per cent of B.O.D., including some suspended, and 95 per cent of hexane solubles, and produced a liquor with suspended solids of only 100 p.p.m., a reduction of over 99 per cent. When the pH in this lot of waste was adjusted to about 7.9 by carbon dioxide, only 1 per cent of calcium chloride was required to crack the waste, with a resulting supernatant showing approximately the same removals of B.O.D. and grease as the chloride alone, but with suspended solids of only 65 p.p.m. It was found necessary to use 1.2 per cent of calcium hypochlorite, which gave a clarified liquor with hexane soluble removal of 88 per cent, B.O.D. removal of 70 per cent, and suspended solids of 180 p.p.m. (about 98 per cent removal).

On another lot of waste from the same mill, this time produced by the use of synthetic detergents and soda with no soap, 2 per cent of calcium chloride applied at 150° F. with no carbon dioxide reduced the hexane solubles by 94 per cent and the B.O.D. by 65 per cent, with 99 per cent removal of suspended solids. Calcium chloride was added to another portion of the same waste in two steps, in the first of which 0.4 per cent was applied at only 100° F., followed by sedimentation, and then a further amount of 0.2 per cent calcium chloride at the same temperature was added to the supernatant. The final liquor gave results very similar to the one-batch treatment, with slightly higher B.O.D., but lower grease and suspended solids. The net volume of sludge, however, was nearly 30 per cent of the original waste, as compared to about 19 per cent by the single addition method. When the sludges produced by the single and the double addition methods were further concentrated, however, there was found to be little or no difference in volume. Table V gives analytical data for this work.

Fulling Mill

Treatment with calcium chloride gave interesting results from another type of textile waste, this time from a fulling mill. These wastes settled very poorly, with only about 10 per cent reduction in suspended solids af-

ter only 24-hr. sedimentation. The use of carbon dioxide to reduce the pH from 10 to 8.5, followed by addition of 0.05 per cent calcium chloride, after 1-hr. settling gave a supernatant which contained only 65 p.p.m. of suspended solids, a reduction of more than 97 per cent. Almost all of the B.O.D. in the original was in solution and the treatment gave a reduction of only about 25 per cent.

These fulling wastes were then mixed with acid dye wastes produced from the same plant, but plain sedimentation of the mixtures for 24 hr. still removed only 7 per cent of the suspended solids and no effective change in B.O.D. was observed. Carbon dioxide treatment, followed again by 0.05 per cent of calcium chloride, produced in 1 hr. a clear liquor with only 40 p.p.m. of suspended solids, a reduction of nearly 98 per cent. The B.O.D. removal was again only about 15 per cent. The fulling mill waste, either with or without the addition of dye wastes, produced after this treatment a light, fluffy, floating sludge containing a considerable amount of fine fibers, which was readily removed by skimming. The clarified liquors after this skimming were apparently the same blue-gray color as the original waste, but dilution with the water of the receiving stream showed that the intensity of the color had been reduced more than 50 per cent by treatment. Analytical data are given in Table VI.

Rouge Wastes

An optical company in Massachusetts produces a waste which thus far has been found very difficult to treat. The waste contains considerable amounts of very finely divided iron (rouge), small amounts of very finely powdered glass, and considerable amounts of a detergent. It has been observed that the red color thus produced is still visible in the receiving stream 15 mi. below the plant. Plain sedimentation effects comparatively little change in color or in iron content; only the heaviest suspended solids are removed, even after 24 hr. The Experiment Station has cooperated in several experimental studies on coagulation of this waste. Recent experiments on a fairly large scale indicate that the addition of about 2 grains per gallon of lime, followed by 0.3 per cent calcium chloride, will almost completely coagulate the materials in these wastes. It also was found possible to reduce the amount of calcium chloride to 0.15 per cent by the addition of 3 grains per gallon of lime. Other amounts of the two coagulants resulting in a pH from 8.0 to 8.2 were also found to give satisfactory coagulation, but the amounts previously mentioned seemed to be the most economical.

It was found that the B.O.D. in the original waste was only 80 p.p.m., of which only 17 p.p.m. was in solution. The treatment with lime and calcium chloride completely removed suspended

TABLE VI.—Analytical Data for Fulling Mill Wastes

Sample	pH	5-Day B.O.D.		Susp. Sol. (p.p.m.)			
		(p.p.m.)	Rem. (%)	Total	Rem. (%)	Loss	Rem. (%)
Raw wastes	10.0	2,750[1]	—	2,430	—	2,160	—
CO_2 to pH 8.5 + 0.05% $CaCl_2$	7.8	2,100	24	65	97	40	98
Raw wastes mixed with dye wastes	9.8	2,230[2]	—	1,860	—	1,720	—
Mixed water after 24 hr. settling	—	2,200[2]	—	1,740	6	1,690	2
CO_2 to pH 8.6 + 0.05% $CaCl_2$[3]	7.7	1,900	15	40	98	38	98

[1] 2,250 p.p.m. in solution.
[2] 2,120 p.p.m. in solution.
[3] Color intensity reduced 50 per cent; light, fluffy, floating sludge.

TABLE VII.—Analytical Data on Rouge Wastes

Sample	pH	Color	Iron		5-Day B.O.D.		Susp. Sol.			
			(p.p.m.)	Rem. (%)	(p.p.m.)	Rem. (%)	Total (p.p.m.)	Rem. (%)	Lose (p.p.m.)	Rem. (%)
Raw waste	5.9	—[1]	540	—	80[2]	—	840	—	200	—
Settled	7.3	—[1]	103	81	34	58	362	57	22	90
Raw treated with 0.3% $CaCl_2$ + 2 gr./gal. lime	8.2	25	3.2	99	17	78	1	100	0	100
Raw treated with 0.15% $CaCl_2$ + 3 gr./gal. lime	8.0	15	1.4	99+	14	83	0	100	0	100

[1] Still pink after dilution with 50 volumes of river water.
[2] 17 p.p.m. in solution.

B.O.D. The suspended solids in the original waste were about 840 p.p.m. and the results from the two experimental treatments showed 1 and 0 p.p.m. remaining. Iron in the original waste was 540 p.p.m.; results of 3.2 and 1.4 p.p.m. were obtained in the clarified liquors. The most startling results, however, were shown in the reduction of color. The original waste after 50-time dilution with the water of the receiving stream still showed a decided pink. The color in the supernatant obtained by the use of 0.15 per cent calcium chloride was 15 on the platinum-cobalt scale, with no pink whatever remaining. Less than 2 per cent of sludge was obtained with these coagulations. The sludge had a very high percentage of iron still in finely divided form; it does not seem impossible that this material might be recovered for further use. Table VII gives analytical data for this waste.

Several other coagulants were tried on this waste, but none was as satisfactory as the chloride. Lime alone, up to 0.5 per cent, gave good removal of solids, but did not remove all the color. Magnesium chloride required prohibitive doses. Various iron salts in high concentrations gave good coagulation, but the supernatants contained undue amounts of iron.

Experimental use of calcium chloride and carbon dioxide has been continued on tannery wastes and laundry wastes; both show the possibility of effective treatment. The results thus far, however, have been on a laboratory scale only and it seems advisable to defer discussion of treatment of these wastes until larger-scale experiments can be run.

Summary

1. The results obtained in full-scale continuous practice using calcium chloride in wool waste treatment seem to be as satisfactory as those shown in preliminary experiments.

2. The mechanism of the process is believed to depend on the formation of calcium soaps. It seems to be equally effective with soaps, syndets, and mixtures. The amount of calcium chloride required in actual practice is generally less than was predicted in experimental work. This apparently resulted in postponement or elimination of the use of carbon dioxide, although it is probable that its use would reduce chemical cost.

3. The step-wise addition of calcium chloride seems to offer strong possibilities of reduced costs.

4. The process, primarily developed for the treatment of wool scouring wastes, has shown usefulness with other wastes containing soaps or syndets.

Reference

1. McCarthy, J. A., "A Method for Treatment of Wool Scouring Wastes." *Sewage Works Jour.*, **21**, 1, 75 (Jan., 1949).

RAG, ROPE, AND JUTE WASTES FROM SPECIALTY PAPER MILLS *

I. Physical and Chemical Characteristics

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The specialty paper mills utilizing rag, rope, and jute as stock produce wastes in the form of cooking liquors and beater wash waters. Practically no information is available regarding the characteristics and strengths of the wastes or the feasibility and methods of treatment. Under a grant from the National Council for Stream Improvement (of the Pulp, Paper and Paperboard Industries, Inc.) an extensive study over a period of several years was made concerning the origin of the wastes, surveys of mills, determination of the quantities, sanitary characteristics, and organic composition of the wastes, followed by load distribution of the cooking liquors in relation to the beater washings, and chemical, anaerobic, and aerobic treatment of the wastes. The results obtained are presented in condensed form in a series of short papers in an effort to indicate the possibilities of treatment and the difficulties to be expected.

Rope

Old ropes are imported mainly from shipyards, where they are used as "fenders" for tugboats and as "holding lines" for ships. These ropes are contaminated with a variety of greases, oils, salts, and dirt. After being sorted and cut, the most contaminated ropes are given a more extensive cooking and washing treatment. The first cooking is usually with kerosene. This cooking waste is very dilute and weak; because of its low pollutional load its treatment was not studied. The grease-free ropes are cooked next in the same rotary cookers with 10 to 20 per cent by weight of caustic soda, soda ash, or combinations of the two. Some mills also use up to 5 per cent Na_2SO_3 in the cookers, as well as more kerosene to remove the last traces of grease. Live steam at a temperature of about 260° F. is continually blown through the cookers for about 8 hr. The cook liquor is drained from the rotary cookers and discharged to the sewer. This waste is highly concentrated and pollutional. The cooked ropes are then transferred to elliptical rotary beater washers, in which they are washed and beaten in hot and, finally, cold water for a total of about 3 hr. The beating part of the washing process causes some suspended fibers to be discharged into the overflowing washing waste. The washing waste is the greatest volume waste from the mill and, therefore, contributes a considerable pollutional load to the total mill effluent. The cooked, beaten, and washed ropes are now ready to be formed into paper on the paper machine.

Rag

In general, the more diversified rag stock consists of fibers which had originally undergone quite extensive treatment to make shirts, underwear, tablecloths, etc., but most of which had since been in contact with extreme contamination. The dirty ones are contaminated with almost anything imaginable. Even the clean ones are varied and consist of cotton, linen, silk,

* Paper of the Journal Series, New Jersey Agricultural Experiment Station.

rayon, or wool, and may be dyed any color. About 10 per cent by weight of caustic soda and some soda ash are added to the rag cookers along with live steam at 40-lb. pressure (220° to 250° F.) The rags are cooked for about 9 hr., the cook liquor is drained, and the cooked rags are washed in a manner similar to that outlined for ropes. Although the cook liquor is more concentrated and objectionable, the daily flow of washing waste is the greatest single source from the plant.

Jute

Jute mills obtain their furnish mainly from old burlap bags. Some of the bags have previously been filled with such materials as flour, tar, coal, wood chips, and sugar. In general, these bags are not so contaminated as the ropes or rags. Jute bags, unlike the ropes and rags, are cooked in the rotary washers for 3 hr. with about 10 per cent by weight of lime, and live steam at about 180° F. Because lime is a weaker alkali than caustic soda or soda ash, and because the cooking time is not so long, the jute cooking liquor waste is the least pollutional of the three.

Physical and Chemical Characteristics

In general, the more intensive the cooking process, the darker is the color of the waste. Rag cook liquors are colored from brown to black, rope liquors are brown, and the jute cook liquors are tan to brown. The beater washing wastes have the same general hue, but are much more dilute. The cooking liquors all have pronounced, disagreeable, characteristic odors, but the wash waters are almost odorless. All the cooking liquors are hot, concentrated, and very alkaline, with pH values of 11 or above. The typical alkalinity component values (Table I) show that the alkalinity is an important chemical characteristic of cooking liquors.

The rag cook liquor alkalinity is about one-half hydroxyl and one-half carbonate; the rope liquor, two-fifths hydroxyl and three-fifths carbonate; and the jute liquor, one-fourth bicarbonate and three-fourths carbonate. The quantity of acid required to neutralize rag cook liquor is 3 times that required to neutralize rope cook liquor and 38 times that required for jute cook liquor.

TABLE I.—Alkalinity Fractions in Cooking Liquors from Rag, Rope, and Jute Mills (Expressed as $CaCO_3$)

Type of Cook	Total Alk. (p.p.m.)	-OH Alk. (p.p.m.)	$-CO_3$ Alk. (p.p.m.)	$-HCO_3$ Alk. (p.p.m.)
Rag	47,000	25,400	22,000	0
Rope	19,200	8,000	11,200	0
Jute	2,600	0	1,840	760

Quantities and Pollutional Loads

Cooking liquor wastes are discharged from the paper mills in relatively small volumes containing high concentrations of solids and 5-day B.O.D. Beater wash-water wastes are discharged in relatively large volumes containing low concentrations of solids and 5-day B.O.D. It is also significant that the quantity of solids and B.O.D. in the wash waters decreases as the washing proceeds.

The cooking liquors range in volume from about 1,500 to 4,000 gal. per ton of product produced (Table II) and contain from 120 to 356 lb. of B.O.D. The beater wash-water volumes range from about 20,000 to 80,000 gal. per ton of product or about 5 to 53 times the volumes of cooking liquors discharged. They also contribute up to 3 times the quantity of total solids and from 1 to 4 times the quantity of B.O.D. as compared to the cooking liquors. These results show the importance of considering wash waters as well as cooking liquors in the waste treatment plans. The average total volumes of both wastes amount to about 73,000 gal. per ton of product containing 0.5 to 1.33 tons of total solids

TABLE II.—Average Volumes and Pollutional Loads of Cook Liquors and Beater Wash Waters per Ton of Paper

Source	Quantity (gal.)	Total Solids (lb.)	Susp. Solids (lb.)	B.O.D. (lb.)
Rope cook	2,100	698	5	215
Rag cook	1,460	1,168	79	356
Jute cook	4,070	244	44	120
Rope wash	72,000	662	272	998
Rag wash	80,000	1,435	395	351
Jute wash	61,000	678	237	196
Total rope	74,100	1,360	277	1,213
Total rag	81,460	2,603	474	707
Total jute	65,070	922	281	316
Paperboard mill	10,000	169	31	33

and about 750 lb. of 5-day B.O.D. per ton of paper manufactured, equivalent to about 4,500 people per ton of paper. This means that a medium-sized specialty mill making 25 tons of paper a day will produce about 50,000 lb. of total solids and 18,750 lb. of 5-day B.O.D. per day, corresponding to the waste discharged by about 12,500 people. The average 5-day B.O.D. in the specialty mill cook liquor and beater wash waste is about 22 times that contained in paperboard mill waste.

Sanitary Analyses

A comparison of some of the important sanitary characteristics of rope, rag, and jute cook and wash wastes (Table III) shows that there is a general relationship between the alkalinity, B.O.D., and total solids in all three cooking liquors. Although they all have approximately the same pH value, the rag cook liquor has about 11 times the methyl orange alkalinity of the jute cook liquor and about twice the rope cook liquor alkalinity. A total solids comparison of the three liquors shows approximately the same relationship between total solids as between alkalinity. This relationship also holds for the B.O.D. of the three liquors, except that the rag liquor B.O.D. is about 2.5 instead of 2 times the rope cook liquor B.O.D.

In general, the relationship of 11:2:1 represents the inter-relationships of alkalinity, total solids, and 5-day B.O.D. of rag, rope, and jute cooking liquor wastes, respectively. Only the rag cook liquor has sufficient nitrogen to support biological life in a treatment process. Of the total solids in the three cooking liquors, the rope and rag liquors are 13 and 11 per cent, respectively, higher in dissolved matter than the jute cook liquor. Rope and jute cook liquor solids are 56 per cent volatile, whereas the rag solids are somewhat higher in volatile matter.

A comparison of the three beater wash-water wastes shows that the jute waste has about twice the alkalinity of rope or rag wastes, a considerably higher pH value, but the lowest B.O.D., indicating the relative ineffectiveness

TABLE III.—Important Sanitary Characteristics of Rag, Rope, and Jute Mill Cooking Liquors and Beater Wash-Water Wastes

Characteristic	Jute		Rope		Rag	
	Cook	Wash	Cook	Wash	Cook	Wash
pH	12	11.2	10.8	8.7	12	8.1
Alkalinity, as $CaCO_3$ (p.p.m.)	2,850	574	18,000	350	31,655	264
B.O.D. (p.p.m.)	3,381	385	12,125	1,250	29,225	526
Total solids (p.p.m.)	7,200	1,300	45,000	1,100	96,000	2,200
Total vol. solids (%)	56	56	56	64	64	64
Dissolved solids (%)	82	65	95	59	93	73
Total nitrogen (p.p.m.)	126	6	157	21	1,270	44
B.O.D.: Total nitrogen	27:1	65:1	88:1	60:1	23:1	12:1

of lime to remove dirt when compared with caustic soda or soda ash. The lime leaves a portion of the pollutional material precipitated in the fibers or unattached, whereas the caustic solubilizes the impurities, which are easily washed out. The jute and rope wash waters contain about the same quantity of total solids, whereas the rag waste contains about twice as much. The average percentage of dissolved solids in the beater wash wastes (65 per cent) is considerably lower than in the cooking liquors (90 per cent). Only the rag beater wash waste contains sufficient organic nitrogen to support adequate biological life in a treatment process. The presence of nitrogen-base dyes and ammonium salts from the human body in the rags probably contributes the larger part of the nitrogen found in the rag wastes.

Organic Composition of Cooking Liquors

The method of Waksman and Stevens (1) was modified (2) and used in the proximate analysis of the various organic constituents found in the cooking liquors. Table IV shows that the bulk of the organic solids are soluble in the cold-water fraction after extraction with petroleum ether. The further breakdown of this fraction for reducing sugars and proteins showed no reducing sugars and only a small percentage of protein matter (Table V). A complete breakdown of the cold-water soluble fraction showed that lignins, volatile carbonates, volatile acids, and complex polysaccharides make up the major portion of this fraction, and that the total volatile matter was completely accounted for in the jute and rope cook liquors, but not in the rag liquor. The jute cook liquor contains about 4 times as great a percentage of volatile acids as the rag and rope liquors, but expressed on a p.p.m. basis, the rag liquor contains the highest and jute liquor the lowest. The lignin content of the rope liquor is about twice that of the rag and jute liquors. Because volatile acids are readily available (up to a certain concentration) as biological food and lignins are not readily decomposable by microorganisms, these two substances, found in varying amounts in all three wastes, might affect results in biological treatments. Also, the rag cook liquor contains some residual grease, which was not extracted by the petroleum ether in the first extraction. It is probable that the rag cook liquor contains highly saponified grease, which must be hydrolyzed with acid before extraction in order to effect its removal.

TABLE IV.—Distribution of Jute, Rope, and Rag Cooking Liquor Solids in Various Solvents

Type of Cook Waste	Percentage of Original Solids Soluble in				
	Petrol. Ether	Cold Water	Hot Water	95% Ethyl Alcohol	2% HCl
Jute	1.1	77.1	4.0	1.1	16.8
Rope	3.8	92.8	2.6	0	0
Rag	3.3	89.4	7.6	0	0

TABLE V.—Breakdown of Jute, Rope, and Rag Cooking Liquor Solids Soluble in Cold Water

Type of Cook Waste	Total Solids in Cold H_2O (p.p.m.)	Vol. Matter (%)	Components of Vol. Matter in Cold Water, as % of Vol. Matter					
			CO_2	Grease	Lignin	Vol. Acids (As HAc)	Complex Poly-saccharides	Protein (Total N ×6.25)
Jute	5,540	68.8	30.0	0	21.8	40.9	10.9	4.5
Rope	37,000	54.3	25.4	0	39.4	14.8	10.6	6.4
Rag	85,800	58.4	24.6	7.6	24.3	10.4	3.6	3.8

Hydrolyzation of the saponified grease was not attempted for fear of changing the character of other dissolved organic matter.

Summary

A study of specialty paper mill processes producing jute, rope, and rag cooking liquor and wash-water wastes, and the physical and chemical characteristics and quantities of these wastes, show that two wastes must be considered—namely, the low volume, odorous, alkaline, and very pollutional cooking liquor and the high volume, rather dilute beater wash water. The total volume of cooking liquors and wash waters discharged averages 73,000 gal., and contains about 750 lb. of B.O.D. and about 2,000 lb. of total solids per ton of paper produced. The pollutional characteristics of the waste from a specialty mill are equivalent to about 4,500 people per ton of paper. An approximate analysis of the organic constituents showed that lignins, volatile acids, complex polysaccharides, some greases, proteins, and hemicelluloses comprise the major portion of the organic matter in cooking liquors.

There is a general relationship between total alkalinity, B.O.D., and total solids in the cooking liquors. The wastes, with the exception of rag beater wash water, do not contain sufficient organic nitrogen to support adequate biological life in a treatment process.

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MAKE YOUR HOTEL RESERVATIONS FOR THE FSIWA SILVER ANNIVERSARY MEETING

The Hotel Statler at New York City will be the headquarters for the Federation's Twenty-Fifth Annual Meeting, to be held in October. An outstanding Silver Anniversary program is being planned for the four-day meeting.

Requests for room reservations should be addressed directly to the hotel. It should be noted that the technical program will open on Monday morning, October 6, and will close at noon on Thursday, October 9. However, the usual inspection trip will this year be scheduled for the afternoon of October 9, after the close of the meeting.

WRITE NOW FOR YOUR RESERVATIONS!

CHEMICAL AND ANTIBIOTIC WASTES TREATMENT AT WILLOW ISLAND, WEST VIRGINIA *

I. Present Chemical Wastes Treatment

By John F. Vogler

Sanitary Engineer, Willow Island (W. Va.) Plant, Calco Chemical Division, American Cyanamid Company

The Willow Island plant of the Calco Chemical Division, American Cyanamid Company, is located on the Ohio River about 24 river miles upstream from Parkersburg, W. Va. This plant commenced operation in 1947 and currently employs 430 people in the production of such diversified fine chemical products as melamine (used for melamine-urea and melamine-formaldehyde resins); iron blue, chrome yellow, chrome green, and molybdate orange pigments; brighteners; folic acid; and pharmaceutical intermediates. Operations are under J. W. Dykes, plant manager. J. F. Bourland is assistant manager and B. S. Blitz is chief plant engineer.

The plant water supply is obtained from two 15-ft. Ranney wells extending through the gravels on the river bank to radial collectors 25 ft. below normal river level. The well water is clear and cool, with chemical characteristics more constant and favorable than those of the river water. The entire plant water supply is chlorinated to a system residual of 0.1 p.p.m. With the exception of boiler feed water treatment and base-exchange softening for melamine process water, chlorination is the only treatment necessary for the water supply. The water, however, is quite aggressive and is distributed in an asbestos-cement pipe underground system with cement-lined cast-iron building piping. Three 100,000-gal. water towers 150 ft. high (one for soft water, one for fire water, and one for manufacturing water) float on the distribution system. Long-range planning calls for ultimate water requirements of 20 m.g.d.; the basic water and effluent systems have been designed accordingly. The two existing wells yield a total of 5.5 m.g.d. An additional Ranney well is presently being constructed on an adjacent island in the Ohio River and will boost the plant water supply to 10.0 m.g.d.

Existing Treatment Facilities

The present effluent collection system (Figure 1) consists of a sanitary sewer system, a manufacturing effluent and storm-water system, a 36-in. vitrified tile interceptor, and a compositing lagoon. Sanitary sewage is collected separately and discharged into the interceptor. The combined manufacturing effluent and the storm water from about 85 acres of developed plant property also discharge into the interceptor and flow by gravity 2,000 ft. to the treatment unit.

This unit (Figure 2) consists of an earthen basin, roughly rectangular in plan, 600 ft. long, 520 ft. wide, and 15 ft. deep. The surface area is 7.2 acres, capacity 27.5 m.g., detention period 8 days at present flows. The walls have a 3 to 1 side slope, a 5-ft. free-board, and a minimum thickness of 10 ft. Stone riprap is provided above and below the waterline to prevent wave erosion. The 36-in. interceptor discharges into a wooden inlet flume and deflection

* A symposium of three papers presented at 1951 Annual Meeting, West Virginia Sewage and Industrial Wastes Assn.; Charleston, W. Va.; Oct. 3–4, 1951.

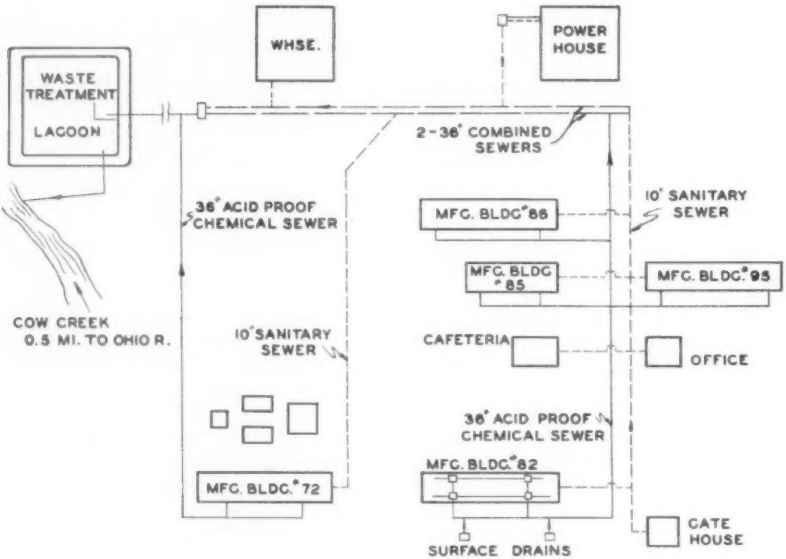

FIGURE 1.—Sewer system at Willow Island plant, Calco Chemical Division.

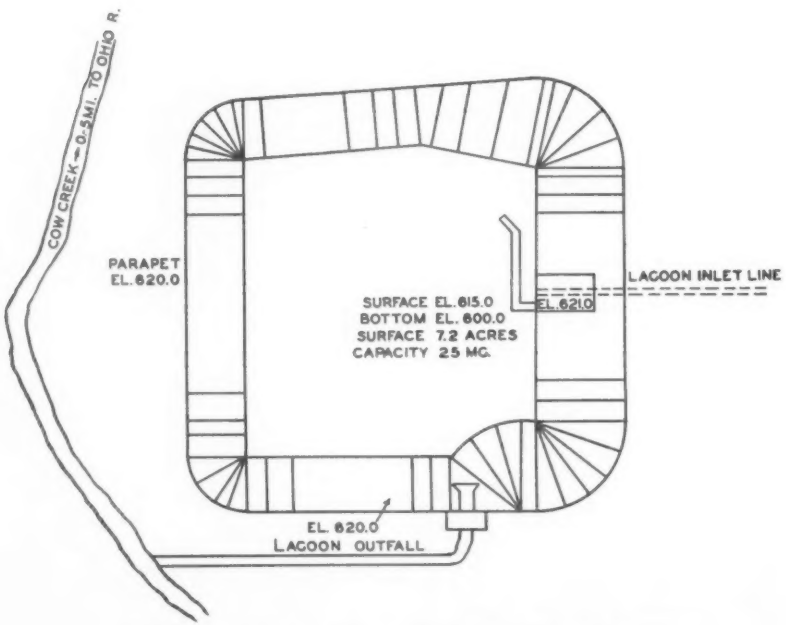

FIGURE 2.—Willow Island chemical effluent disposal lagoon.

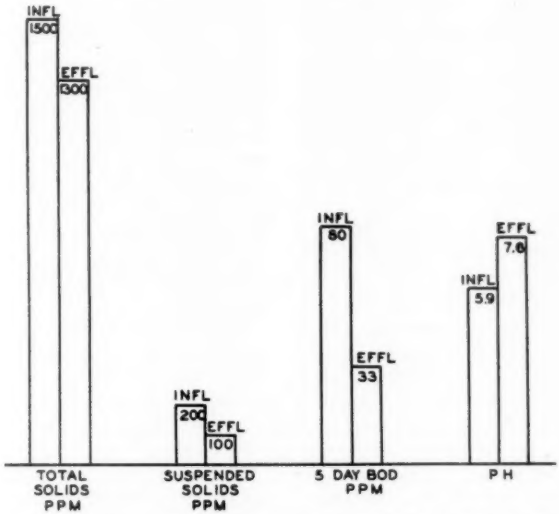

FIGURE 3.—Average results of weekly analyses of Willow Island effluent lagoon (Jan., 1950 to Apr., 1951).

baffle structure, which dissipates the incoming velocity head and gives the raw effluent a rotary path through the lagoon, thus obtaining efficient utilization of its entire volume. The effluent passes under a skimming baffle, through a wooden outlet flume, and over a 90° V-notch weir. The weir is equipped with a continuous float-operated water level recorder and a sampling device whereby a small effluent flow is bled continuously into a 55-gal. composite sampling drum. After passing over the weir, the effluent spills 13 ft. into a baffled masonry mixing chamber, falls 14 ft. down a cascade into Cow Creek, and flows 0.5 mi. to the Ohio River, at a point 162 river miles below Pittsburgh. Here the Ohio has a drainage area of 26,850 sq. mi. and over the last 10 years has had an annual minimum average daily flow of 1,400 m.g.d., an annual minimum average monthly flow of 4,600 m.g.d., and an annual mean flow of 25,000 m.g.d. Even at minimum daily flows a dilution factor of more than 400:1 is obtained at this point. The location is ideal for the plant in that, with good normal control, downstream pollution may be avoided.

Performance

The raw Willow Island wastes consist largely of spent mother liquors, filtrates, column slops, wash and cooling waters, sanitary sewage, and storm drainage. The principal pollutants are organic by-products, acids, alkalies, and salts. Flow in 1950 was 3.4 m.g.d., but has since been reduced to about 2.5 m.g.d. as a result of an intensive water conservation program. Raw wastes (Figure 3) are fairly high in color and suspended matter. The B.O.D. varies from 46 to 150 p.p.m., averaging 80 p.p.m.; pH varies from 2.5 to 8.0, with an average of 5.9. Total and suspended solids are rather constant at 1,500 and 200 p.p.m., respectively.

The lagoon effluent is pale green in color, slightly turbid, with a B.O.D. of about 33 p.p.m., a pH of 7.6, and total and suspended solids of 1,300 and 100

p.p.m., respectively. Laboratory control is maintained through complete sanitary analyses of weekly 24-hr. composites of the influent and final effluent, and weekly samples of Cow Creek and of the Ohio River above and below the plant. Monthly bacteriological examinations are made of effluent and river samples.

Recommended unit B.O.D. loadings for sewage lagoons have been variously reported in the literature (1) (2) to range from 15 to 65 lb. per acre-foot per day, with 40 lb. per day as a rough average. Under such loadings, B.O.D. reduction of about 50 per cent and low-coliform effluents are obtained. The 1950 Willow Island lagoon influent load was roughly 2,300 lb. of B.O.D. per day, which is equivalent to 27 lb. per acre-foot per day. Under such conditions average B.O.D. and suspended solids reductions of about 50 per cent were obtained. This has prevented pollution below the plant.

In fact, the treatment system took whatever wastes the production department dumped into the sewer, and the effluent has been undetectable in the river by observation or laboratory examination of samples. No odor troubles have been experienced in the lagoon with the chemical and sanitary wastes. It is the home of frogs, turtles, and an occasional snake, and is frequently visited by flocks of wild ducks, especially during the spring and fall migrations—truly a waste water man's Shangri-La.

Then, in 1950, came the decision of management: Aureomycin would be fermented at Willow Island. This created a new and larger problem, the nature of which is outlined in the subsequent paper.

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II. Aureomycin Wastes

By J. M. Brown

Sanitary Engineer, Pearl River (N. Y.) Plant, Lederle Laboratories Division, American Cyanamid Company

Lederle Laboratories Division of the American Cyanamid Company is located in Pearl River, N. Y., and currently employs more than 4,000 people in producing biologicals, pharmaceuticals, and antibiotics, and in the fermentation of B-12, a growth-producing substance being found valuable in the preparation of animal feeds. The effluent problems created by the transformation of the Lederle plant from one producing vaccines and biologicals into a major antibiotics plant has been described in the literature (1) and need not be repeated in detail here. The type of waste suddenly changed from one composed of animal wastes (blood and liver pulp) into one of strong B.O.D., containing many tons of organic material in solution for each ounce of finished product. The waste problem is further complicated by the location of the Pearl River plant on the watershed of a public water supply serving half a million people. The stronger industrial wastes, with a small amount of domestic sewage, are pretreated by the company, merged with the untreated weaker wastes, given a final disinfecting dose of chlorine, and discharged to the municipal sewage treatment plant, where further treatment is provided before discharge into the Hackensack River.

Aureomycin wastes at Willow Island will fall into four groupings, deter-

mined by the origin of the wastes. These are:

1. Strong fermentation beers or filtrates of high B.O.D., ranging from 4,000 to 7,000 p.p.m. Aureomycin, like penicillin, is produced by fermentation in a medium containing sugars, corn steep liquor, and nutrient salts, which aid the growth of the organisms. When the mycelium is separated from the mash, the filtrate is passed through layers of Magnesol which absorbs the B–12, a growth-producing vitamin. The spent filtrate is then discharged to the sewer. This is one of the major B.O.D. sources.

2. Washings of the floor and equipment, ranging in B.O.D. from 600 to 1,500 p.p.m. and contributing a large part of the hydraulic load.

3. Inorganic solids, including filter cake from the cleaning of pre-coat vacuum filters. Filter-Cel is built up on the wire mat of a vacuum filter to act as a pre-coat. When this layer is removed, a portion of the filter aid (diatomaceous earth) is sewered.

4. Chemical wastes. These include acids and alkalies lost by accident, and butanol and brine from the refining of the drug. Most of the butanol is recovered for re-use, but a significant quantity is sewered as wastage, liquors too weak to warrant redistillation, and still heels. The magnitude of the butanol loading may be more clearly illustrated by observing that it exerts about 1.5 lb. of B.O.D. per 1.0 lb. of butanol content, that some of the still heels contain 50,000 p.p.m. B.O.D., and that the total sewered load from this source may reach as high as 3,000 lb. of B.O.D. daily. The brine may amount to as much as 60 tons per day of salt.

The Pearl River problem is further complicated by barometric condenser water, which it is understood has been avoided at Willow Island. Successful disposal of barometric condenser water required much dilution by the receiving stream. These wastes are of very high volume and of moderate B.O.D., ranging only from 60 to 120 p.p.m. The contamination of barometric condenser water through entrainment or volatilization of the evaporating liquids is impossible to prevent in plant practice. Experience indicates that as high as 25 per cent of the B.O.D. of the evaporating liquors may be lost to the condensate.

The mixture of all of the aureomycin

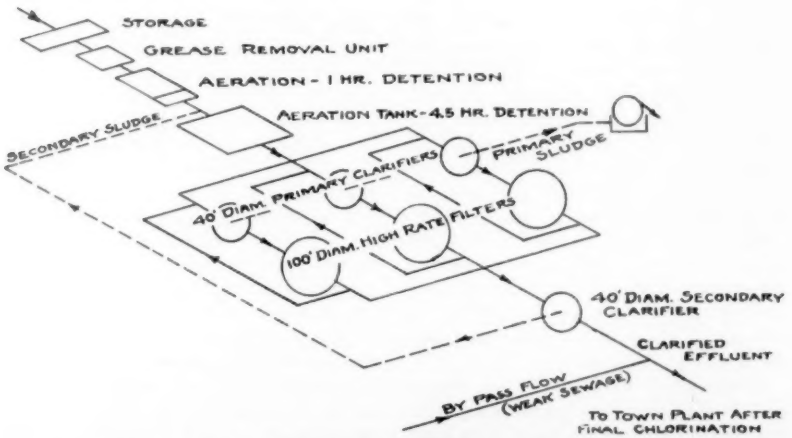

FIGURE 4.—Lederle Laboratories waste treatment plant flow diagram.

wastes at Pearl River, plus the liver plant and certain experimental plant wastes, gives a total flow of about 0.425 m.g.d., ranging from 2,500 to 3,000 p.p.m. B.O.D. Lederle's treatment system (Figure 4) consists of a storage tank, pH equalization, grease flotation by aeration, plain aeration for a 4- to 5-hr. detention period, three 40-ft. diameter clarifiers, three 100-ft. diameter high-rate trickling filters operating in parallel, and a secondary clarifier.

The side-hill location of the filters permitted direct placement of the screened stone from trucks. Ponding on the first two filters was believed to be due in part to accumulations of fines and diatomaceous earth in the areas compacted by the truck wheels. To provide a basis of comparison, the stone for the third filter was screened on the premises and placed on the bed with a belt conveyor.

Chlorination facilities are provided within the treatment system and, in addition, all final effluent is given a disinfecting dose of chlorine before being released to the municipal plant.

Sludge from the primary and secondary clarifiers is dewatered on a 6-ft. by 6-ft. vacuum filter. The diatomaceous earth in the sludge at times may cause the solids in the sludge to reach 9 to 12 per cent and the ash content to climb to 70 per cent. Under these conditions, chemical dewatering is not needed. Under other conditions, dewatering is accomplished with ferric chloride and lime. Obviously, because of high ash content, such sludge is not suitable for disposal by digestion.

The manufacture of antibiotics is an ever-changing process. Effluent treatment requires unrelenting vigilance to keep pace with the manufacturing departments and offers a continuing challenge to the sanitary engineer.

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III. Design of the Additional Treatment Facilities

BY GUY E. GRIFFIN

Sanitary Engineer, Central Engineering Department, American Cyanamid Company

When the problem of treating the new aureomycin wastes was presented to the Central Engineering Department in September, 1950, and assigned to this author, the requirements were for a temporary means of treating the wastes from a limited antibiotic fermenting operation until such time as a permanent disposal plant could be designed and built for treatment of the wastes for the full-scale fermenting operation. Effluent quality was specified to be, in general, equal to the effluent of a primary treatment plant for municipal sewage.

Preliminary work at Willow Island and Pearl River was undertaken with the result that certain basic data were established as a basis of design. The 5-day B.O.D. of the raw wastes would vary from 5,000 to 8,000 lb. daily. A temporary treatment plant would be required to treat about 40 per cent of the ultimate load, pending construction and operation of the permanent plant. The 30-min. chlorine demand of the raw wastes would be about 600 p.p.m. A 1 to 100 dilution of these wastes with the existing chemical plant final effluent, described by Vogler in a preceding paper, would result in a mixed effluent of 60 to 75 p.p.m. B.O.D. and 3 to 6 p.p.m. 30-min. chlorine demand. The fermentation wastes, chlorinated to a 30-min. chlorine residual of 0.3 p.p.m., and then diluted 1 to 100 with the chemical plant final effluent, would have a relative stability of only a few

hours. On the other hand, these wastes chlorinated after this dilution, would have a relative stability of 5 to 10 days. At that time the volume of the chemical plant effluent was estimated to be 5 m.g.d. in late 1951, and its 5-day B.O.D. load, exclusive of the aureomycin wastes, was estimated to be about 900 lb. daily.

In addition to these limited but specific basic data, there was free access to an accumulation of treatment information collected at Pearl River, similar information on Ohio River characteristics, and the present problem at Willow Island. Armed with this information, the following program was followed:

Temporary Treatment

For the temporary treatment of the fermentation wastes, it was decided to provide equalizing storage for the initial flow of 63,000 g.p.d., add continuously to this storage a high-pH disinfecting dose of lime to promote stability during storage, to discharge from storage at a uniform rate to provide equalized dispersion into the final chemical plant effluent, and to chlorinate the final mixture to control the development of the B.O.D. (Figure 5). It was estimated that the final B.O.D. without chlorination would be about 95 p.p.m. and that with chlorination it would be inhibited to the point where its effect would be negligible. Sludge would be periodically pumped from the storage tank and disposed of on the premises.

Accordingly, a 25,000-gal. wooden receiving tank was constructed and equipped with two 400-g.p.m. automatic float and alternator controlled pumps.

FIGURE 5.—Schematic diagram of temporary treatment for antibiotic wastes at Willow Island.

Lime was added to the pump basin from a manually controlled conventional dry feeder. Constant discharge was ensured by means of a floating adjustable submerged orifice. A permanent outfall about 1,500 ft. long was laid to serve this and the permanent plant. A 400-lb. chlorinator was provided at the final effluent well to ensure adequate final disinfection and stabilization of the mixed effluent. To serve this isolated machine, we piped chlorine gas under pressure across the fields for about 1,200 ft.

This temporary unit was placed in operation in July, 1951, and has given good service.

Permanent Treatment Plant

With the completion of the fermentation plant, the volume of wastes would increase from 63,000 to 160,000 g.p.d. This, as described in the preceding paper by Brown, would consist of fermentation filtrates, slops, wash-up water, a small amount of sanitary sewage, and the other wastes sewered by the fermentation and filtration units. The average rate of flow would be 111 g.p.m., but, because fermenters occasionally "go wild" and must be dumped at a more rapid rate than normal, it was necessary to design for the higher rate of 450 g.p.m., with 600 g.p.m. as the hydraulic maximum. The influent 5-day B.O.D. load would be 8,000 lb. per day. The solids from the diatomaceous earth and wasted mycelium would cause 600 cu. ft. per day of sludge containing 8 to 10 per cent solids.

The stream pollution laws of West Virginia and the Ohio River Water Sanitation Compact wisely leave the detailed requirements for industrial waste treatment largely to the discretion of the State Water Commission. Therefore, the problem was discussed with

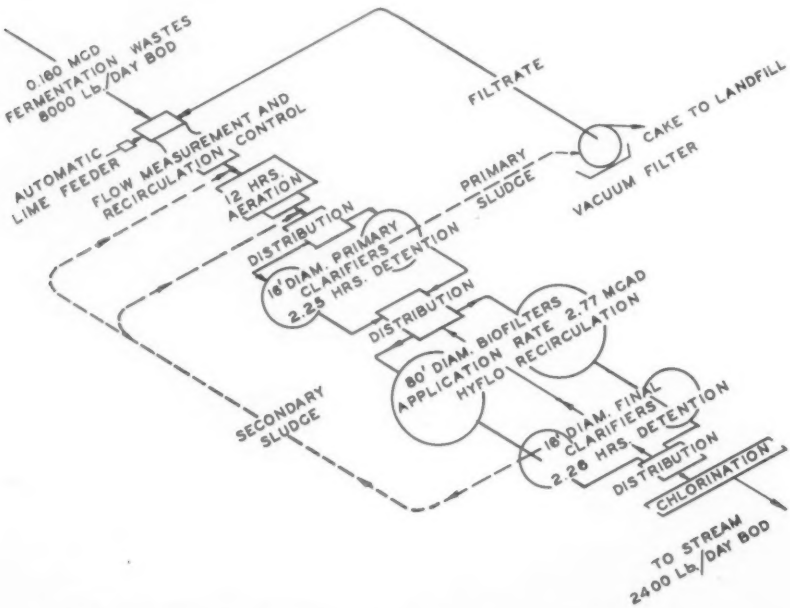

FIGURE 6.—Sequence of permanent treatment steps in disposal of Willow Island antibiotic wastes.

the Commission's engineers, and the conclusion was reached that the logical approach would be to consider the problem as being similar to sanitary sewage, insofar as solids and B.O.D. were concerned. Therefore, the following objectives were adopted for the final effluent from the entire plant:

Settleable solids—negligible
Suspended solids—not more than 80 p.p.m.
5-day B.O.D.—not more than 100 p.p.m.

Consideration was given to chemical *versus* biological treatment for reducing the strong wastes to this lower level. Brown's work at Pearl River precluded the use of chemical treatment as a major treatment method, again confirming the story which has been repeated over and over again in sewage disposal, chemical precipitation will aid in removing suspended solids, but it has little effect upon colloidal or soluble B.O.D.

Biological treatment of similar wastes at Pearl River was proving fairly satisfactory. Therefore, this method was adopted for Willow Island. From the refining end of the antibiotic manufacturing process, certain wastes would contain solvents mixed with salt, which would be detrimental to biological treatment. Therefore, it was planned to sewer these directly to the lagoon and it was estimated that the contaminated brine would contribute 900 lb. additional B.O.D. to that already in the lagoon effluent, making a total of about 1,800 lb. daily. Some reduction would undoubtedly take place there, but no credit was taken for it in design planning.

The adopted limit of 100 p.p.m. B.O.D. in a combined flow of 5.16 m.g.d. to the Ohio River would amount to 4,300 lb. B.O.D. per day. Subtracting the 1,800 lb. in the lagoon effluent left 2,500 lb. possible in the treatment plant effluent. Starting with 8,000 lb. per day, this left 5,500 lb. per day to be removed by the treatment plant (Figure 6).

Plant Units

Experience at Pearl River indicated that the treatment plant should have the following devices and units (see Figure 7):

Flow measurement.
pH control.
Holding and aeration unit.
Sedimentation.
Trickling filters with recirculation.
Secondary sedimentation.
Chlorination.
Return of secondary sludge ahead of aeration or primary sedimentation.
Dewatering of the combined sludge by vacuum filtration after conditioning.
Disposal of sludge by land fill or burial.

Experience with an aeration tank at Pearl River had indicated B.O.D. removals up to 30 per cent of the applied load. For the Willow Island plant an allowance of 25 per cent removal by aeration and sedimentation was adopted for design, based on 12-hr. detention and air at 1 cu. ft. per gal. of flow. Two tanks, each 20-ft. by 21-ft. wide by 13 ft. 6 in. water depth, are provided. They are to be equipped with swing diffusers, to which air will be supplied by two blowers. Primary sedimentation is provided by two 16-ft. diameter tanks, having 5-ft. sidewater depth and equipped with sludge collectors and skimming devices. At average flow, the detention period is 2.25 hr. and the overflow rate is 400 g.p.m. per sq. ft.

Removal of 25 per cent of the influent 8,000 lb. of B.O.D. leaves 6,000 lb. per day applied to the trickling filters and final sedimentation units. To meet the effluent B.O.D. requirements, 3,600 lb. of this 6,000 lb. must be removed by the filters and final settling. After much consideration, several conferences and consultations, a

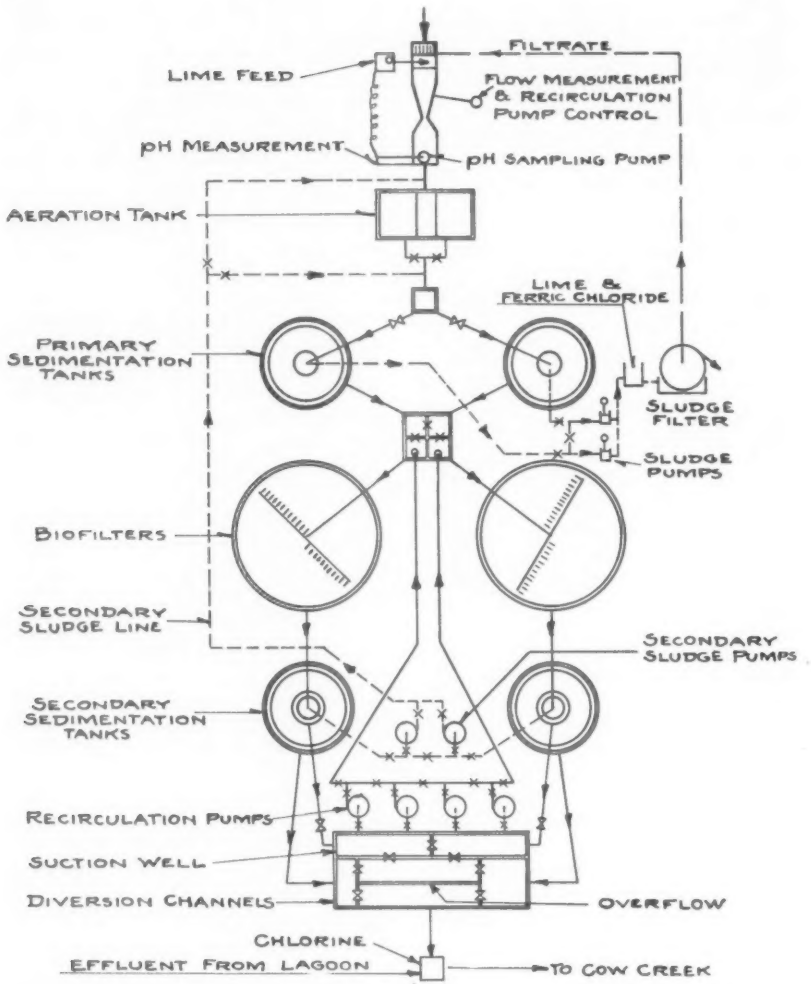

FIGURE 7.—Control details, Willow Island permanent antibiotic wastes plant.

design loading of 4,300 lb. per acre ft. on a 6-ft. deep filter was selected. An average flow recirculating ratio of 3 volumes of filter effluent to 1 of raw wastes was adopted.

On a volume basis, this design loading is 2.69 lb. B.O.D. per cubic yard of stone. The rate of liquid application is calculated to be 2.77 m.g.a.d. To meet these requirements, two 80-ft. diameter filters equipped with rotating distributors were designed.

Unlike the Pearl River filters, which have no retaining walls, those at Willow Island are designed with walls and provided with gates in an outlet chamber so that they may be flooded for treatment, or to minimize silt deposits in case of extremely high flood stages of the Ohio River. Much thought was

given to the filter media. Specifications were written for the use of hard stone sized for 1½-in. to 3½-in., with not over 20 per cent less than 2½ in., to be washed at the plant site and placed on the bed by conveyor belt or other means. The passage of trucks or bulldozer over the stone in the bed was prohibited, based on Pearl River experience. It was found that there was no nearby source of hard stone and the specifications were amended only to allow the use of screened and washed furnace slag, sized from 2 in. to 4 in. This media has been quite successful in the chemical waste trickling filters at Dow Chemical Company's Midland, Mich., plant.

The secondary sedimentation tanks, also equipped with sludge collectors, are of the same dimensions as the primary tanks. They are provided with central launders for recirculation and the outlet weir overflow will be equal to that of the primary tanks.

Sludge from the primary and secondary clarifiers will contain, as Brown has previously observed, an ash content too high for successful digestion. Therefore, it will be pumped from the clarifiers and dewatered on a 6-ft. by 6-ft. vacuum filter. Dewatering will be aided by pretreatment with ferric chloride and lime. Preliminary work indicates that these filters may be efficiently operated with excess lime at high pH values (10.8 to 11.4). If so, the cake will be stable and will be disposed of as land fill. If lower pH filtration is necessary, its quick putrefaction will require burial by sanitary land fill methods. The vacuum filter filtrate will be returned to the treatment plant.

The final effluent will flow by gravity to the lagoon outlet chamber, mix there with the lagoon effluent, flow out to Cow Creek and thence to the Ohio River, about one-half mile distant. Final chlorination facilities will be provided to ensure bacterial control and downstream stability.

Additional design features of the plant are automatic pH control, automatic step operation of the filter circulating pumps to maintain a fairly uniform rate of dosage, and flexibility to provide for parallel or series operation of the trickling filters. A laboratory fully equipped for sanitary, chemical, physical, and biological tests is provided for control of the plant.

It is felt that the plant will fulfill its assignment. As with most industrial waste problems, there is no standardized treatment for chemical wastes, and the design of such disposal plants must be changed from job to job to meet the changing operations of industry.

Personnel

The antibiotic wastes treatment plant described herein was designed under the direction of W. A. Weber, assistant chief plant engineer, Calco, Bound Brook, N. J., who was in charge of the engineering for the Willow Island antibiotic project. J. A. McCarthy, director, Lawrence Sewage Experiment Station, Massachusetts State Department of Health; J. M. Brown, of Lederle; and L. L. Hedgepeth, of Calco, served as advisors on the waste treatment plant design. The Central Engineering Department is directed by D. H. W. Feleh, chief engineer, American Cyanamid Company.

NUTRITIONAL REQUIREMENTS IN THE BIOLOGICAL STABILIZATION OF INDUSTRIAL WASTES

III. Treatment with Supplementary Nutrients *

By E. N. Helmers,† J. D. Frame, A. E. Greenberg, and C. N. Sawyer

The results of previous work (2) have shown that the nutritional requirements for biological stabilization of certain industrial wastes can be supplied by treatment in combination with domestic sewage. In many instances, however, wastes deficient in nutritional elements must be treated without benefit of mixture with a sufficient amount of sewage. Such is frequently the case in industrial treatment plants employing biological processes. Industrial plants usually have sufficient domestic sewage to provide biological seed and a part of the nitrogen and phosphorus requirements, but supplementary nutrients often must be added for satisfactory treatment.

The purpose of this paper is to provide a basis for determining the magnitude of nutritional deficiencies in activated sludge treatment under such circumstances and to establish the proper amounts of supplementary nutrient material that must be added to achieve required treatment efficiencies. The experimental method used in these studies has been described (1).

Industrial Wastes

Three nutritionally deficient industrial wastes were used in these studies—cotton kiering waste, rope pulping waste, and brewery waste. They were obtained from the same sources as the wastes used in the studies with domestic sewage (2). Analyses of the wastes and of the domestic sewages used in small quantities as seed are given in Table I.

The cotton kiering waste used in Run E had very nearly the same composition as that in the corresponding run with domestic sewage, Run C. Rope waste alone was used in Run H, instead of the mixture of rag and rope pulping wastes used previously in Run D. The rope waste of Run H had about the same B.O.D. as the Run D mixture, but less nitrogen and somewhat more phosphorus. The Run K brewery waste was about one-fourth the strength of the Run I brewery waste, but the B.O.D. to total nitrogen ratios and B.O.D. to total phosphorus ratios were about the same in both cases.

To ensure uniformity of the waste load, sufficient cotton kiering waste and rope waste were obtained to last an entire experimental run. The pH of these wastes was adjusted from 7.0 to 7.5 before use. The brewery waste was obtained periodically throughout the run.

Experimental Method

As before, activated sludge experiments were conducted with a constant aeration period of 7 hr. and 1,500 p.p.m. aeration solids. All sludges were acclimated before routine analysis of samples was started.

Experimental conditions for the three runs are shown in Table II. The B.O.D. loadings were about 70 lb. per 1,000 cu. ft. aeration capacity per day,

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TABLE I.—Industrial Waste and Domestic Sewage Analyses

Factor	Run E		Run H		Run K	
	Cotton Kiering	Domestic Sewage[1]	Rope Waste	Domestic Sewage[1]	Brewery Waste[1]	Domestic Sewage[1]
5-day B.O.D. (p.p.m.)	2,745	193	14,850	200	521	371
Total nitrogen (p.p.m.)	97	26.0	64	26.0	5.7	29.3
Organic nitrogen (p.p.m.)	85	12.0	60	12.0	5.4	13.5
Total phosphorus (p.p.m.)	15.6	4.96	6.9	5.4	1.85	5.80
Soluble phosphorus (p.p.m.)	—	3.25	—	—	0.73	3.80
pH	12+	—	12+	—	—	—
B.O.D./Tot. N ratio	28	7.4	233	7.7	92	13
B.O.D./Tot. P ratio	176	39	2,150	37	282	64

[1] Average values.

TABLE II.—Experimental Conditions

Tube No.	Temp. (°C.)	Waste[1] (%)	Supplementary Nutrients			B.O.D. Loading[4]	Ratio of Appl. B.O.D. to	
			Sewage (%)	Nitrogen[2] (p.p.m.)	Phosphorus[3] (p.p.m.)		Appl. Tot. N	Appl. Tot. P
(*a*) Cotton Kiering; Run E								
1A	10	10	5	0	0	35.6	26	158
2		10	5	2	0	35.6	22	158
3		10	5	4	0	35.6	19	158
4		10	5	6	0	35.6	17	158
1B	20	20	5	0	0	70.0	27	166
2		20	5	5	0	70.0	22	166
3		20	5	10	0	70.0	18	166
4		20	5	15	0	70.0	16	166
1C	30	20	5	0	0	70.0	27	166
2		20	5	3	0	70.0	24	166
3		20	5	6	0	70.0	21	166
4		20	5	9	0	70.0	19	166
(*b*) Rope Waste; Run H								
1	[5]	3.5	5	0	3	66.3	150	152
2		3.5	5	8	3	66.3	45	152
3		3.5	5	15	3	66.3	29	152
4		3.5	5	25	3	66.3	19	152
(*c*) Brewery Waste; Run K								
1	[5]	95	5	0	5	67.4	75	76
2		95	5	5	5	67.4	44	76
3		95	5	15	5	67.4	24	76
4		95	5	25	5	67.4	17	76

[1] Waste plus sewage plus water equals 100 per cent.
[2] Added as $(NH_4)_2SO_4$ in Runs E and H, and NH_4OH in Run K.
[3] Added as KH_2PO_4 in all runs.
[4] Pounds B.O.D. per 1,000 cu. ft. aeration capacity per day.
[5] Each series of four tubes at temperatures of 10°, 20°, and 30° C.

except in the kiering waste run at 10° C., where the loads were 36 lb. per 1,000 cu. ft. The primary variable was the amount of supplementary nitrogen, supplied in the form of ammonium sulfate. No supplementary nitrogen was added to the first tube of each series, and increasing amounts were supplied to each of the other three tubes.

On the basis of previous runs, a sufficient quantity of inorganic phosphorus was added to the feed mixtures in the rope waste and brewery waste runs to supply the requirements of the activated sludge. No supplementary phosphorus was added during the kiering waste run, because treatment with domestic sewage had shown that the kiering waste was not deficient in available phosphorus.

In Runs E and H, tap water was added to the feed mixtures to reduce the B.O.D. loading on the treatment process. In actual practice, the B.O.D. loadings would be reduced by weaker waste streams and wash waters. Five per cent domestic sewage was incorporated in all feed mixtures to represent the small sewage load that is often treated along with stronger wastes in an industrial waste treatment plant. This small amount of sewage provided bacterial seed and, possibly, nutritional elements that may have been required in trace amounts.

In the treatment of the rope waste and brewery waste, difficulty was experienced with sludge bulking. This condition has frequently been observed in the treatment of high-carbohydrate wastes. Sludge bulking was successfully controlled by addition of chlorine to the feed mixture at each of the three daily feedings. This procedure would be comparable to the continuous chlorination of the influent to the aeration tanks. During the rope waste run, 5 p.p.m. chlorine was added to the feed mixture, and during the brewery waste run 2 p.p.m. chlorine was added.

During the brewery waste run, a duplicate set of four tubes was fed at 20° C. The feed mixtures were exactly the same, but one set was chlorinated and the other was not. The results obtained from these two series indicated that the chlorine had little effect on the nutritional requirements of the sludge, but aided appreciably in controlling sludge bulking and in improving its dewatering characteristics. Bulking gradually decreased in the unchlorinated tube with maximum nitrogen supplementation, but bulking

TABLE III.—Nitrogen Content of Effluents

Waste	Inorganic N (p.p.m.)			Organic N (p.p.m.)		
	10° C.	20° C.	30° C.	10° C.	20° C.	30° C.
Cotton kiering	0.4	0.7	0.6	5.6	7.3	8.2
	0.5	0.5	0.6	6.1	6.7	8.8
	0.4	0.5	0.5	6.2	7.3	7.6
	0.4	0.7	0.5	7.2	8.4	6.9
Rope	1.9	2.6	1.6	2.6	3.2	3.6
	2.2	2.0	1.9	3.6	3.9	3.3
	2.1	2.1	2.2	5.3	6.1	3.9
	6.8[1]	5.6[1]	5.6[1]	4.1	5.6	5.5
Brewery	0.6	0.3	0.4	3.3	2.0	3.2
	0.4	0.2	0.3	5.1[2]	2.2	4.7
	0.4	0.7	1.6	7.7[2]	3.5	7.7[2]
	13.6[1]	11.7[1]	13.1[1]	6.7[2]	2.8	4.6

[1] Considered as indicating a nitrogen excess.
[2] Values considered high due to turbidity of effluent.

TABLE IV.—Phosphorus Content of Effluents

Waste	Soluble P (p.p.m.)			Total P (p.p.m.)		
	10° C.	20° C.	30° C.	10° C.	20° C.	30° C.
Cotton kiering	0.54	0.73	0.75	1.01	1.11	1.09
	0.38	0.31	0.49	0.69	0.61	1.04
	0.28	0.27	0.34	0.66	0.43	0.73
	0.34	0.28	0.22	0.64	0.42	0.45
Rope	2.70	2.84	2.26	3.30	3.14	2.89
	1.59	1.56	1.47	1.97	1.76	2.24
	0.73	0.71	0.82	1.11	1.41	1.09
	0.19	0.42	0.62	0.49	0.73	1.07
Brewery	4.25	3.57	4.12	4.84	4.10	4.94
	2.85	2.41	2.67	3.44	3.62	4.51
	2.12	1.20	1.16	2.34	1.76	2.39
	2.03	0.77	1.33	2.20	1.35	2.33

was brought under control faster in the equivalent tube that was chlorinated. The detailed results of the unchlorinated series are not included in this paper.

Results

Effluent Nitrogen and Phosphorus

The inorganic nitrogen contents of most of the effluents were quite low (Table III). A nitrogen deficiency was indicated in all cases in the cotton kiering waste run, and only the tubes with maximum supplementary nitrogen contained an excess in the other two runs. As in previous work, temperature had little effect on the amount of residual nitrogen; but nitrification occurred at 20° and 30° C., whereas very little nitrification was noted at 10° C. Appreciable organic nitrogen was present in all effluents, even though a nitrogen deficiency occurred. This observation indicates that a considerable portion of the influent nitrogen was not available for activated sludge growth.

Table IV shows the phosphorus contents of the effluents. The soluble phosphorus residuals in the brewery waste run indicate a definite excess in all cases. Although some of the residuals in the other two runs were rather low, reasonably constant phosphorus contents of the sludges and computed phosphorus requirements (Tables VI and VII) indicate that appreciable phosphorus deficiencies did not exist.

Nitrogen Requirements

Nitrogen requirements were computed using both sludge growth and influent-effluent analyses as a basis. A fairly good check was obtained between the two methods for the cotton kiering and rope waste runs, but the agreement was not so good in the brewery waste run because of sludge carryover in the effluent. The results of these calculations are shown in Table V, in which the maximum nitrogen requirements as determined in previous runs with domestic sewage are included for comparison.

Theoretically, as the amount of supplementary nitrogen is increased, the nitrogen requirement should increase until the maximum requirement is reached as indicated by avaible nitrogen in the effluent. An increase in nitrogen requirement occurred with increasing supplementation in all three runs, but the maximum requirement was not always reached. As none of the effluents in the kiering waste run contained excess available nitrogen, the maximum requirements were not supplied at any temperature. Excess nitrogen was present in the rope waste

TABLE V.—Nitrogen Requirements

Waste (%)	Supp. N (p.p.m.)	Temp. (°C.)	Nitrogen Requirements[1]		Max. N Requirements[1,2]
			Sludge Basis	I_n–E_n Basis	
(*a*) Cotton Kiering Waste					
10	0	10	1.9	2.0	
10	2		2.6	2.5	
10	4		2.7	3.3	
10	6		3.3	3.6	5.6
20	0	20	2.3	2.5	
20	5		3.2	3.5	
20	10		3.6	4.3	
20	15		5.5	5.0	6.2
20	0	30	2.3	2.3	
20	3		2.5	2.8	
20	6		3.0	3.5	
20	9		3.7	4.2	6.2
(*b*) Rope Waste					
3.5	0	10	>0.6	—	
3.5	8		1.7	1.7	
3.5	15		3.1	2.8	
3.5	25		4.3[3]	4.2[3]	3.8
3.5	0	20	>0.9	—	
3.5	8		>1.8	>1.4	
3.5	15		2.0	2.3	
3.5	25		2.2[3]	3.7[3]	7.7
3.5	0	30	1.1	—	
3.5	8		2.0	1.4	
3.5	15		2.5	2.5	
3.5	25		2.8[3]	3.6[3]	5.9
(*c*) Brewery Waste[4]					
95	0	10	1.5	0.9	
95	5		2.3	1.6	
95	15		3.8	3.0	
95	25		4.3[3]	2.6[3]	5.9
95	0	20	1.8	1.0	
95	5		2.8	2.0	
95	15		4.8	3.7	
95	25		4.9[3]	3.6[3]	4.6
95	0	30	1.2	0.7	
95	5		1.6	1.5	
95	15		4.4	2.7	
95	25		4.4[3]	3.0[3]	5.3

[1] Pounds of nitrogen required per 100 lb. of waste B.O.D. stabilized.

[2] Values determined in previous runs; see reference (2).

[3] Nitrogen excess, see Table III.

[4] Computed values low because of sludge carryover.

TABLE VI.—Phosphorus Requirements

Waste (%)	Supp. P. (p.p.m.)	Temp. (°C.)	Phosphorus Requirements[1]		Max. P Requirements[1,2]
			Sludge Basis	I_p–E_p Basis	
(*a*) Cotton Kiering Waste					
10	0	10	0.30	0.31	
10	0		0.33	0.44	
10	0		0.32	0.44	
10	0		0.33	0.44	0.98
20	0	20	0.41	0.44	
20	0		0.50	0.53	
20	0		0.46	0.54	
20	0		0.63	0.54	1.20
20	0	30	0.38	0.43	
20	0		0.39	0.44	
20	0		0.42	0.50	
20	0		0.42	0.54	1.11
(*b*) Rope Waste					
3.5	3	10	>0.15	>0	
3.5	3		0.30	0.40	
3.5	3		0.33	0.52	
3.5	3		0.49[3]	0.68[3]	0.53
3.5	3	20	>0.29	>0	
3.5	3		>0.35	>0.45	
3.5	3		0.37	0.44	
3.5	3		0.41[3]	0.57[3]	0.82
3.5	3	30	0.19	0.05	
3.5	3		0.35	0.19	
3.5	3		0.42	0.45	
3.5	3		0.44[3]	0.49[3]	0.51
(*c*) Brewery Waste					
95	5	10	0.53	0.60	
95	5		0.69	0.87	
95	5		0.83	1.00	
95	5		0.92[3]	1.09[3]	1.01
95	5	20	0.62	0.65	
95	5		0.89	0.71	
95	5		1.21	1.04	
95	5		1.24[3]	1.07[3]	1.10
95	5	30	0.57	0.43	
95	5		0.68	0.51	
95	5		1.20	0.96	
95	5		1.07[3]	0.98[3]	1.49

[1] Pounds of phosphorus required per 100 lb. of waste B.O.D. stabilized.

[2] Values determined in previous runs; see reference (2).

[3] Nitrogen excess.

TABLE VII.—Process Efficiency and Activated Sludge Analyses

Supp. N (p.p.m.)	Temp. (° C.)	B.O.D. (p.p.m.)		Sludge Growth (p.p.m./day)	Sludge Volume Index (Mohlman)	Sludge Analyses		
		Infl.	Effl.			N(%)	P(%)	V_m(%)
				(*a*) Cotton Kiering Waste				
0	10	285	49	198	139	4.78	0.79	90
2		285	45	218	123	5.92	0.80	90
4		285	39	214	105	6.52	0.81	90
6		285	34	234	84	7.30	0.77	91
0	20	560	63	542	109	4.38	0.79	88
5		560	48	610	90	5.41	0.86	88
10		560	28	605	72	6.39	0.84	91
15		560	29	790	133	7.46	0.87	90
0	30	560	50	560	83	4.37	0.72	88
3		560	49	534	84	4.86	0.77	88
6		560	40	551	89	5.84	0.83	89
9		560	31	615	72	6.45	0.74	89
				(*b*) Rope Waste				
0	10	530	>250	106	83	3.21	0.77	86
8		530	211	196	144	5.57	1.03	88
15		530	137	290	62	8.46	0.94	91
25		530	106	410	82	8.97	1.02	91
0	20	530	>250	154	430	2.94	0.94	84
8		530	130	280	214	5.06	1.00	88
15		530	94	264	76	7.17	1.25	90
25		530	67	268	77	7.73	1.43	88
0	30	530	147	250	150	3.72	0.62	84
8		530	88	300	199	6.15	1.05	86
15		530	47	347	178	7.11	1.18	86
25		530	44	348	130	7.92	1.26	88
				(*c*) Brewery Waste				
0	10	514	151	267	80	4.17	1.47	96
5		514	94	347	58	5.46	1.66	95
15		514	36	403	64	8.97	1.96	96
25		514	62	381	64	10.08	2.15	97
0	20	514	33	466	151	3.67	1.21	97
5		514	27	586	64	4.58	1.45	94
15		514	14	559	83	8.35	2.11	95
25		514	10	546	69	8.75	2.25	95
0	30	514	30	357	225	3.29	1.53	97
5		514	21	347	153	4.52	1.88	92
15		514	24	466	85	9.07	2.48	90
25		514	23	472	75	8.92	2.18	93

and brewery waste tubes with maximum nitrogen added, but agreement with the previously calculated maximum requirements was achieved only at 10° C. in the rope waste run and at 20° C. in the brewery waste run. Sludge carryover in the effluents is the probable reason calculated requirements did not equal the maximum requirements in the other tubes with maximum supplementation.

Phosphorus Requirements

Phosphorus requirements are shown in Table VI. Values calculated by the two methods are in good agreement. Although an excess of phosphorus was believed to have been present in all cases, phosphorus requirements were less than the maximum requirements determined in previous runs except when there was an excess of available nitrogen.

In the rope waste and brewery waste runs, maximum phosphorus requirements were attained in most cases when there was a nitrogen excess. Because a nitrogen excess was not supplied in the kiering waste run, the maximum phosphorus requirements were not reached. A phosphorus deficiency probably would have occurred in the kiering waste run if an excess of nitrogen had been supplied.

Process Efficiency and Sludge Analyses

The effects of adding supplementary nitrogen are best shown by the data in Table VII. The most marked effect is the pronounced increase in nitrogen content of the activated sludge. In the rope waste run, the sludge nitrogen content increased from about 3 per cent with no supplementation to 8 per cent with maximum supplementation. A similar increase occurred in the

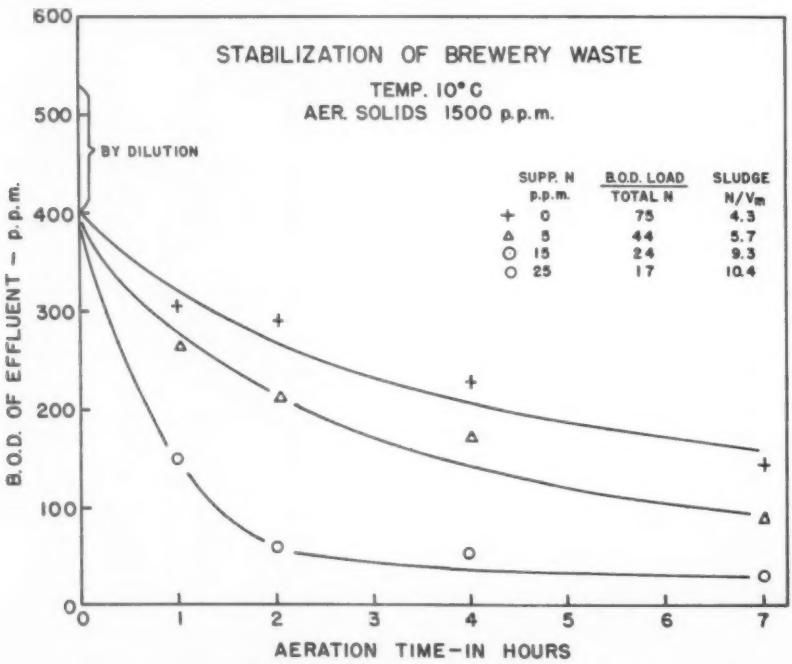

FIGURE 1.—Effect of available nitrogen on rate of B.O.D. removal at 10° C.

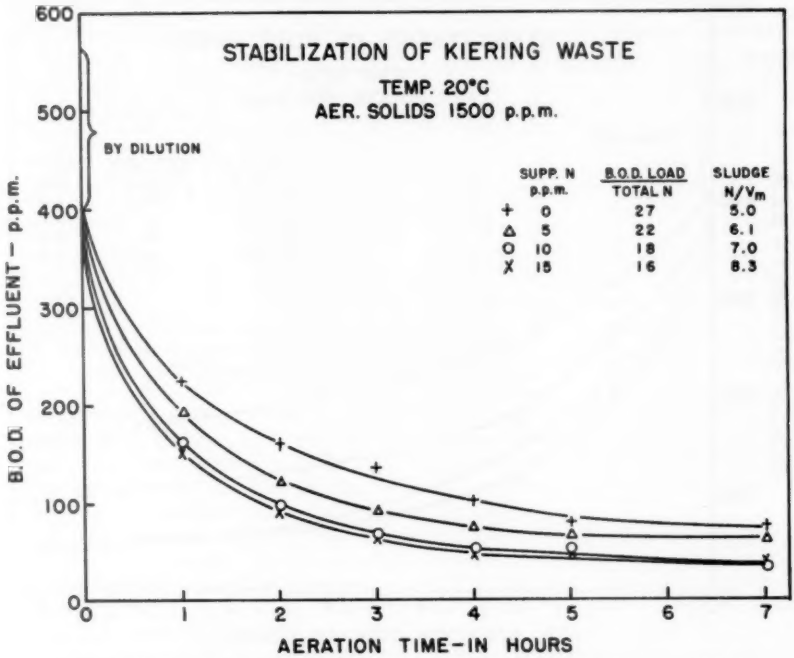

FIGURE 2.—Effect of available nitrogen on rate of B.O.D. removal at 20° C.

other two runs. On the other hand, the variation in sludge phosphorus content was small because of the excess supplied. The volatile matter was high in all cases with the highest values occurring in sludges developed on brewery waste.

The addition of supplementary nitrogen also resulted in better settling sludges as indicated by lower sludge volume indices. Another observation of some importance was that the sludges were much easier to dewater by filtration as the amount of supplementary nitrogen was increased. The time required to filter sludges produced in the brewery waste run was reduced by more than one-half by the addition of nitrogen. This effect of supplementation would be of importance in a plant employing vacuum filtration in the treatment of excess sludge.

Rates of sludge growth were also affected by nitrogen addition. As nitrogen supplementation was increased, the rate of sludge growth also increased until an excess of nitrogen was supplied. This effect was noted in previous work (2) when these wastes were treated in combination with domestic sewage.

Nitrogen supplementation also resulted in a greater reduction in 5-day B.O.D., as indicated by the effluent B.O.D. values in Table VII. The effect of nitrogen on rate of B.O.D. removal is best shown by the effluent B.O.D. *vs.* aeration-time curves (Figures 1, 2, and 3). For example, Figure 3 indicates that in the stabilization of rope waste at 30° C., the B.O.D. was reduced to 150 p.p.m. after 1.5 hr. aeration with maximum nitrogen supplementation, whereas 7 hr. were required to reduce

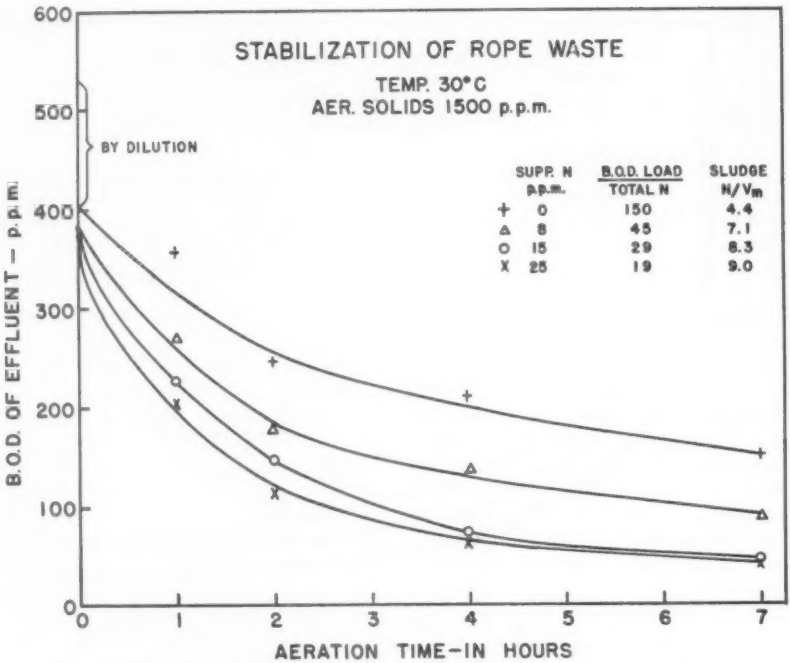

FIGURE 3.—Effect of available nitrogen on rate of B.O.D. removal at 30° C.

the B.O.D. to this same value when no supplementary nitrogen was added. Figures 1 and 2 show similar relationships for the other two wastes studied.

Availability of Organic Nitrogen

Because of sludge carry-over in the effluent, calculations of the availability of organic nitrogen were not very satisfactory for rope and brewery waste. However, the calculated availabilities for kiering waste checked quite well with the previously calculated values from data obtained when cotton kiering waste was treated in mixture with domestic sewage. The percentages of the organic nitrogen utilized from the kiering waste at 10°, 20°, and 30° C. in the studies just reported were 27, 57, and 54 per cent, respectively, as compared with 21, 45, and 70 per cent when treated in combination with domestic sewage (2).

Discussion

Critical Nitrogen Requirements

An interesting feature of Figures 1, 2, and 3 is that they indicate that after some critical amount of nitrogen supplementation has been reached, further increase in nitrogen supply does not improve the rate of B.O.D. removal appreciably. For example, Figure 2 shows that the rate of B.O.D. removal was increased by increasing the nitrogen supplementation from 0 to 10 p.p.m., but increasing supplementation from 10 p.p.m. to 15 p.p.m. resulted in very little additional improvement. This same effect was observed at all temperatures for all three wastes. Consequently, on the basis of B.O.D. removal, little is to be gained by adding supplementary nitrogen in excess of some critical amount.

Critical nitrogen requirements based

TABLE VIII.—Critical Nitrogen Requirements, Based on Rate of B.O.D. Reduction

Waste	Temp. (° C.)	Supp. N (p.p.m.)	N/V_m (%)	Phosphorus Requirement[1]	Critical Nitrogen Requirement[2]
Cotton kiering	10	4	7.2	0.44	3.3
Rope	10	15	9.3	0.52	3.0
Brewery	10	10	9.3	1.00	3.4
Cotton kiering	20	10	[7.0	0.54	4.2
Rope	20	15	[8.0	0.44	2.2
Brewery	20	10	[8.8	1.04	4.2
Cotton kiering	30	6	6.6	0.50	3.5
Rope	30	15	8.3	0.45	2.5
Brewery	30	5	4.9	[0.51	1.6

[1] Pounds of phosphorus per 100 lb. B.O.D. removed.
[2] Pounds of nitrogen per 100 lb. B.O.D. removed.

on rates of B.O.D. removal as determined from Figures 1, 2, and 3 and similar curves are shown in Table VIII. The values given are not precise because of the limited number of nitrogen supplementation increments used in the experimental work, but the agreement between critical nitrogen requirements for the three different wastes is fairly good. The average critical nitrogen requirements based on B.O.D. were 3, 4, and 3 lb. nitrogen per 100 lb. B.O.D. removed at 10°, 20° and 30° C., respectively. These values compare with previously determined (2) maximum nitrogen requirements of 5, 6, and 6 lb. per 100 lb. B.O.D. removed, indicating that maximum requirements do not have to be supplied to produce maximum rates of B.O.D. removal.

Interpretations Based on Nitrogen Content of Sludge

The nitrogen content of the activated sludge would appear to be a reasonable indication of whether or not an activated sludge plant is being operated with a sufficiency of available nitrogen. The B.O.D. studies indicated that the rate of B.O.D. reduction did not decrease appreciably until the nitrogen content of the volatile matter (N/V_m) fell below 7 per cent; therefore, this value would appear to be a useful criterion for diagnosis. If difficulties are believed to be caused by a deficiency of nitrogen, a fast method for determining whether or not this hypothesis is correct would be to determine the nitrogen and volatile matter content of the sludge.

A sludge analysis should prove to be a better diagnostic tool and criterion for operational control than an analysis of the effluent for inorganic nitrogen. An effluent devoid of inorganic nitrogen indicates a nitrogen deficiency, but does not measure the magnitude of that deficiency. These studies have indicated that maximum nitrogen requirements need not be supplied for satisfactory operation. Operation at a slight deficiency could not be controlled by effluent analyses, but control could be attained using sludge analyses.

Phosphorus Requirements

The nitrogen requirement has been emphasized in this discussion, because nitrogen supplementation was the principal variable in the experimental work and phosphorus was provided in excess of sludge requirements. The phosphorus requirement appears to depend somewhat on the magnitude of the nitrogen deficiency because of the effect of a nitrogen deficiency on sludge growth. The phosphorus requirements corresponding to critical nitrogen requirements are shown in Table VIII. Average phosphorus requirements under these conditions were 0.6, 0.7, and

0.5 lb. per 100 lb. B.O.D. stabilized at 10°, 20°, and 30°C., respectively. These values are considerably lower than previously determined maximum phosphorus requirements of 0.8, 1.0, and 1.0 lb. per 100 lb. B.O.D. stabilized (2).

Sludge Growth

The rates of sludge growth shown in Table VII are somewhat less than would have been expected on the basis of Figures 1, 2, and 3 of the second paper of this series (2). Sludge growth increased with available nitrogen; however, in the kiering waste and brewery waste runs, the growths in those tubes with maximum supplementary nitrogen were approximately the same as would have been expected from the relationships given in the preceding paper. The rates of sludge growth in the rope waste run were lower in all cases, especially at 20° and 30°C. This effect is also reflected in low nitrogen requirements. A possible reason for this anomaly may reside in the fact that a considerable amount of chlorine was required to control sludge bulking. It is conceivable that the chlorine may have shifted the assimilative-oxidative relationship toward increased oxidation.

Summary

Laboratory experiments were carried out using activated sludge to study the treatment of certain industrial wastes deficient in nutritional elements without benefit of mixture with large amounts of domestic sewage. Conditions of treatment were designed to be comparable to conditions that might exist in an industrial treatment plant. Supplementary nutrients were added in varying amounts in the form of inorganic salts of nitrogen and phosphorus.

The three industrial wastes studied were cotton kiering waste, rope pulping waste, and brewery waste. All experiments were conducted with three feedings a day followed by 7-hr. aeration periods and with aeration solids concentrations of 1,500 p.p.m. Temperatures were controlled at 10°, 20°, and 30° C. Chlorine was added in some instances to control sludge bulking.

The effect of different amounts of supplementation on rate of B.O.D. removal and other treatment process variables was studied. Critical nitrogen requirements were computed and compared with maximum requirements determined in previous work, and a simple diagnostic method for determining the magnitude of a nutritional deficiency was developed.

Conclusions

The following conclusions are based on activated sludge treatment of nutritionally deficient industrial wastes with the addition of supplementary nitrogen and phosphorus using a 7-hr. aeration period and 1,500 p.p.m. of acclimated sludge solids:

1. Industrial wastes of the nature of those studied can be treated successfully in mixture with as little as 5 per cent sanitary sewage and with B.O.D. loadings as high as 70 lb. per 1,000 cu. ft. aeration capacity per day if nitrogen and phosphorus requirements are supplied by supplementation.
2. Maximum nutritional requirements need not be supplied in order to achieve satisfactory treatment.
3. Critical nitrogen requirements on the basis of B.O.D. removal are estimated to be 3, 4, and 3 lb. per 100 lb. of 5-day B.O.D. removed (or, expressed as the ratio of B.O.D. removed to nitrogen utilized, 33, 25, and 33) at 10°, 20°, and 30° C., respectively.
4. Phosphorus requirements under similar conditions were 0.6, 0.7, and 0.5 lb. per 100 lb. of 5-day B.O.D. removed (or, expressed as the ratio of B.O.D. removed to phosphorus utilized, 167, 143, and 200) at 10°, 20°, and 30°C.
5. A critical nitrogen deficiency

tends to decrease the rate of B.O.D. removal, impair the settling and dewatering characteristics of the sludge, and decrease the rate of sludge growth.

6. The per cent nitrogen content of dried activated sludge based on volatile matter is a good index of nitrogen deficiency. A value of less than 7 per cent is indicative of a critical deficiency.

Acknowledgment

The investigation reported herein was supported by a research grant from the National Institutes of Health, U. S. Public Health Service.

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STUDY TO EVALUATE PLASTIC PIPE FOR WATER USE

Anticipating increased use of plastic pipe in water supply systems—likely to be hastened by metal shortages—manufacturers of extruded plastic products and their raw material suppliers, acting jointly with the National Sanitation Foundation, headquartered at the University of Michigan in Ann Arbor, recently started on research expected to produce authoritative proof that such pipe is not toxic and has the chemical stability necessary for water supply adaptations.

The studies, which will also evaluate the various types and classes of plastic for the making of water pipe, are expected to extend over at least two years. Walter D. Tiedeman, head of the Foundation's testing laboratories, will be in charge. He will work closely with an advisory committee composed of sanitarians and public health officers from various parts of the country and an equal number of representatives of the plastics industry.

Initial tests are being made on 26 samples of pipe made of polystyrene, polyethylene, cellulosic materials, and copolymers of polyvinyl chloride. Part of the research contemplates the feeding of granulated samples to rats and restriction of their water supply to that circulated through the special pipes. Answers will be sought to two main questions: (a) Do any types of tap water become polluted by contact with specific types of plastic; and (b) If there is erosion in plastic pipe, will continued ingestion of the eroded plastic cause pathological changes?

Stream Pollution

PULP MILL LOCATION STUDY IN REGARD TO WATER POLLUTION

By Robert O. Sylvester *

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One of the nation's major pulp producers has been considering the erection of a large kraft-type pulp mill on the Willapa River estuary in southwest Washington. Realizing the pollutional potentialities of a kraft-type pulp mill, and the fact that Willapa Bay is perhaps the best oyster producing area on the West Coast, the company requested the cooperation of the Pollution Control Commission in determining which of the two prospective mill sites under consideration would be most desirable from a waste disposal standpoint; if neither, what other site on the estuary would be more acceptable; and what water quality conditions were then prevalent in the estuarial waters.

Critical water quality conditions occur in the latter part of the summer, due to low river flows and high water temperature. This is the period when salmon migrations normally occur and this, together with the possible effect of toxic components of the waste on shellfish, made it imperative that the waste be discharged at a location providing the greatest quantity of water for dilution.

The survey and study of the Willapa River estuary described herein was made by the survey group of the Pollution Control Commission under the direction of Edward F. Eldridge, director and chief engineer. The period selected was July 6 to August 14, 1950, as this was a period of low steady stream flows with little precipitation. Several subsequent samples were taken in the dry period following August 14 to note any significant change in previous conditions. No significant changes were noted.

Scope of Study and Survey

The scope of the present study and survey was established as follows:

1. To determine the feasibility of discharging the wastes from a kraft-type pulp mill into the Willapa River estuary. (The proposed mill would have all modern and improved types of recovery equipment, including equipment to rid the waste water of most of its toxic properties.)
2. To determine the most suitable point of discharge for these wastes in the estuary.
3. To find the existing quality of the estuarial waters as affected by raw sewage discharge from two cities and by decomposing wood wastes from several saw mills.
4. To determine the dilution available due to river flow and tidal prism in various sections of the estuary and predict the maximum concentration of toxic materials in these several sections.
5. To find the existing bacteriological condition of the estuary and oyster beds at the mouth of the estuary in Willapa Bay (not included in this paper).

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Description of Area

The Willapa River is located in southwest Washington and has a drainage area of some 130 sq. mi. It discharges into the upper end of Willapa Bay, a large bay having a narrow entrance into the Pacific Ocean opposite the river mouth (see Figure 1). River discharge measurements (made only since 1947) indicate a mean annual flow of 613 c.f.s., a minimum flow of 24 c.f.s., and a maximum flow of 10,000 c.f.s. The length of the estuary, or tidal effect from the river mouth, is approximately 15 river miles at high water, or 23 miles at low water.

The two cities located on the estuary discharge their untreated wastes into the estuarial waters. These cities are South Bend and Raymond, having 1950 populations of 1,855 and 4,041 and estimated sewered populations of 1,000 and 3,300, respectively. Several saw mills have log storage areas in the vicinity.

Wood products and fishing are the primary industries of the area, with wood products producing the major economic return. Shellfish growing and harvesting constitute the principal source of livelihood in the fishing industry. In 1949 a total of 22,103,782 lb. of fish and shellfish were landed in the Willapa Bay district. Of this total, 17,400,000 lb. were oysters having a wholesale value of $1,600,000. The Willapa River supports game fish and commercial salmon; a state salmon hatchery is located on the upper river. An annual retail value of $330,000 is placed on the salmon fishery by the State Department of Fisheries.

Willapa Bay is shallow and has large areas of mud flats and oyster beds exposed at low tide. The Willapa River estuary is navigable for ocean-going ships to Raymond, 7 mi. above the high-water mouth, and is navigable for smaller vessels to the limit of tidal effect. The river bottom and banks are of a clay-like brown mud; the mean annual tidal range is 7.8 ft. The principal tributary is the South Fork, which enters at Raymond.

Procedure

It was assumed that the Willapa River estuarial effects would persist out into Willapa Bay until buoy No. 2 (opposite Tokeland) was reached (see Figure 1). The survey and study was carried on along 30.1 bay-river miles, from the mouth of Willapa Bay to 3 mi. above tidal water effects in the Willapa River. Seven shore sampling stations were established, as shown in Figure 1. (Other river sites from which samples were taken were not accessible from shore.) The majority of the data was obtained from the Commission's motor launch, which was capable of navigating all portions of the survey area affected by tidal action.

Determinations at various depths in Willapa Bay and the estuary were made for dissolved oxygen, chlorides, temperature, coliform bacteria, pH, and current movement. Chlorides were determined by the Mohr method and are reported as parts per million of the chloride ion (Cl^-). These serve to indicate the proportions of sea and river water in the area sampled. Current movement was determined by float measurements using finned-bottle floats set at various depths, by using a current meter, and by calculation using cross-section area and volume relationships previously computed. A total of 641 separate determinations were made during the survey period, of which 217 were for chloride and 82 for dissolved oxygen. Also, 126 current meter readings and 12 separate float studies were made. Area, depth, and cross-section values in the bay and estuary were obtained from U.S.C. & G.S. chart No. 6,185, Corps of Engineers' maps showing the latest data on dredged channels in the Willapa River and Bay, and the State Highway Department map of Pacific County, Wash.

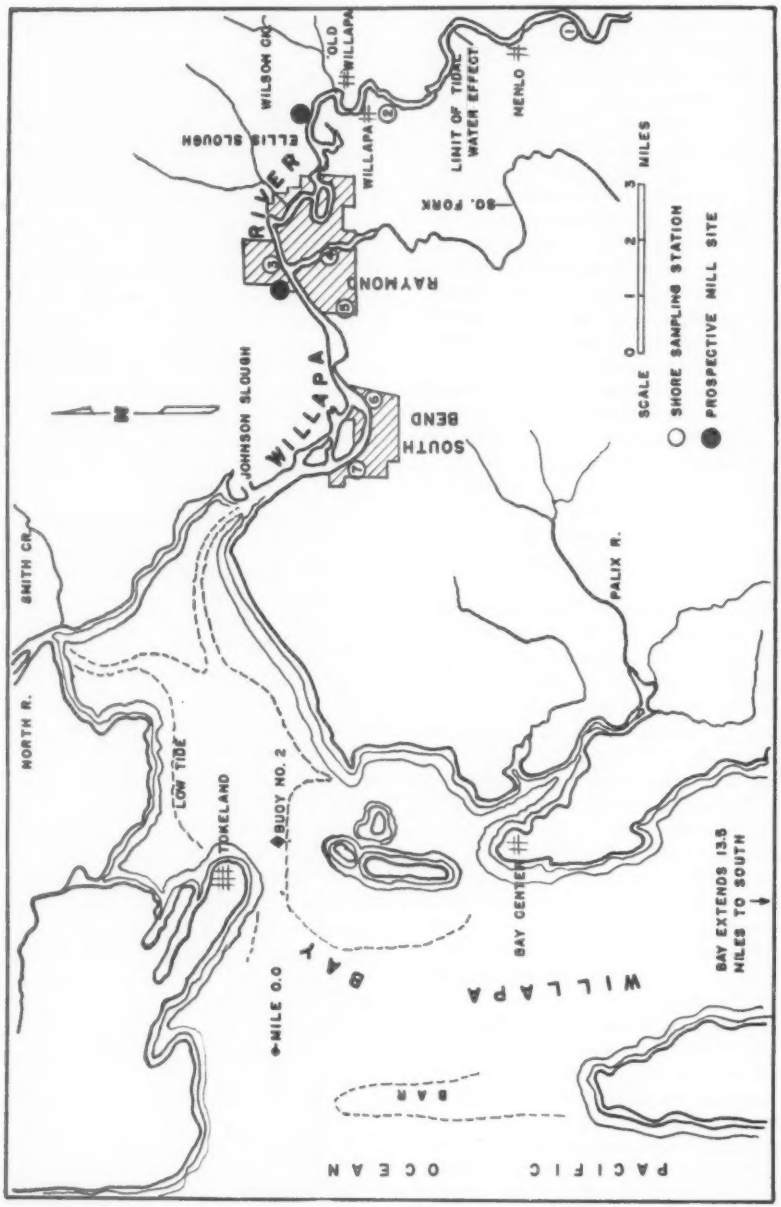

FIGURE 1.—Map of survey area, Willapa Bay and estuary.

Results

River Flows

Figure 2 shows the hydrograph of the Willapa River during the period of record and the flow during the survey period, which averaged about 50 c.f.s. The critical water quality period of low summer flows is clearly shown.

Estuary Volumes

It was necessary to determine estuary volumes between certain arbitrary river stations so that dilution effects, tidal oscillation, detention periods, etc., could be computed. These were determined by planimetering plotted cross-sections and estuary surface areas for 1,000-ft. estuary segments. One-half of the tidal prism (for an average tidal range of 7.8 ft.) was added to the estuary volume below mean lower low water to obtain the average estuary volumes. Figure 3 graphically represents the estuary volume differences progressing upstream and shows that water quantities available for waste dilution do not materially increase until a point about 2 mi. downstream from South Bend is

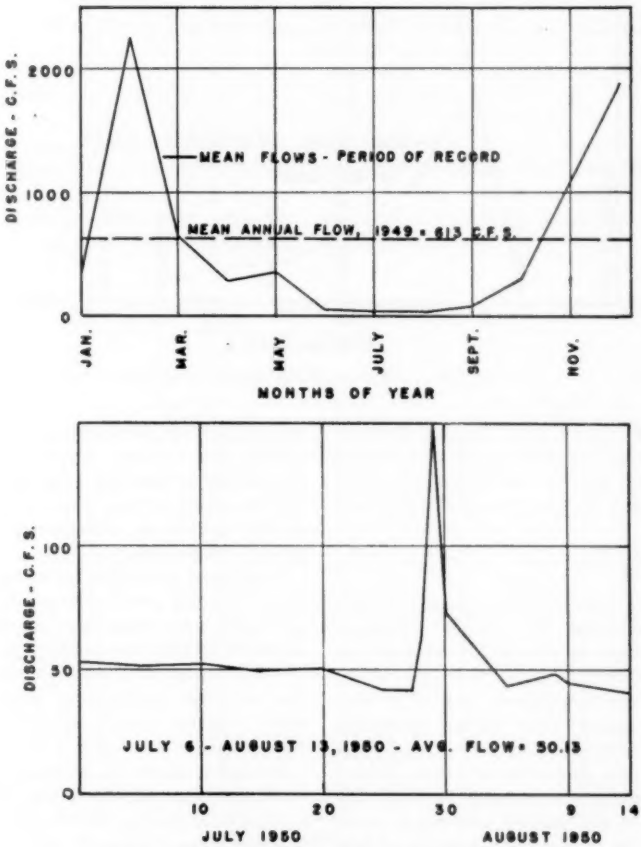

FIGURE 2.—Hydrographs for Willapa River.

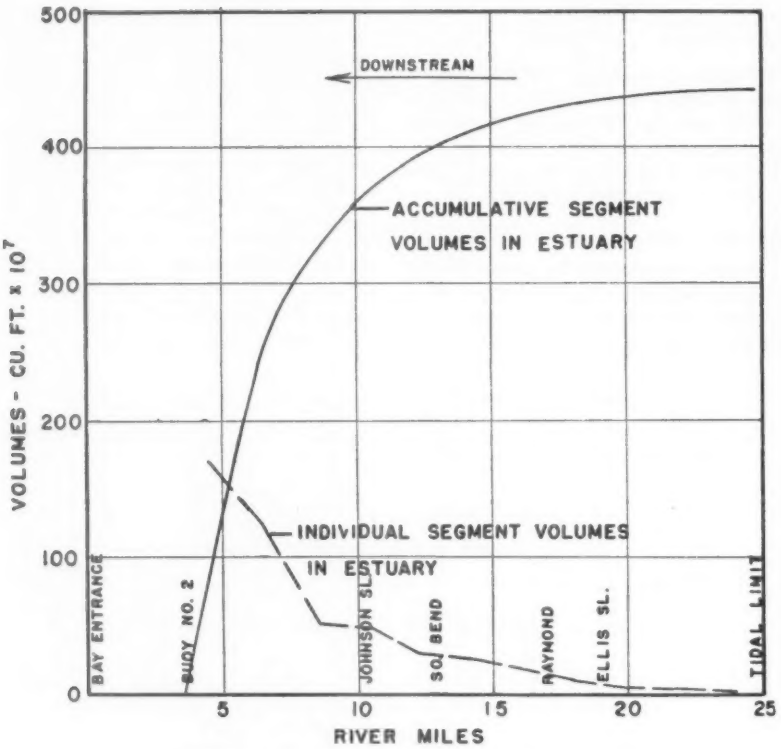

FIGURE 3.—Willapa River estuary volumes.

reached. Calculations showed that the tidal prism constituted 54 per cent of the total estuary volume above buoy No. 2 and 36 per cent above Johnson Slough.

Velocities

Figure 4 shows the average velocities obtained along the estuary. Because the channel is reasonably uniform in dimensions throughout its length, velocities at the downstream end were naturally larger than those upstream. Velocity distribution with depth was similar to a deep flowing river. There was no noticeable average velocity difference in the estuary between a flooding and an ebbing tide, because of low flows in the Willapa River entering the upper end of the estuary. In other words, the estuary current was upstream on a flooding tide and downstream on an ebbing tide, a condition which would not necessarily prevail at high river inflows.

Computed velocities by cross-section area and tidal prism relationships were generally lower than those measured in the field by floats or by current meter. The period of slack water at high and low tide was exceedingly short. The water velocity would reverse in direction within a very few minutes.

Figure 4 shows an average velocity at South Bend of 0.75 m.p.h. during a normal tidal half-cycle of 6.2 hr. Thus, if waste were discharged into the estuary at South Bend on the beginning of

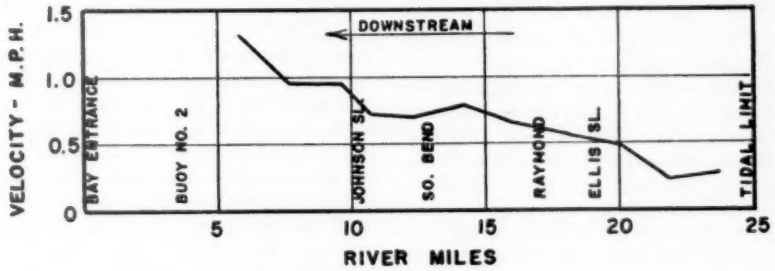

FIGURE 4.—Average estuary velocity.

the flood or ebb tide, it would be carried 6.2 (0.75) = 4.6 mi. upstream or 4.6 mi. downstream, respectively.

Temperature and pH

Temperature and pH measurements showed no appreciable change with depth, indicating good mixing in the estuary. The soft, colored Willapa River water had an average pH of 6.8 and a temperature of 20.5° C., whereas the Pacific Ocean water at the Willapa Bay entrance had a temperature of 14.5° C. and a pH averaging slightly greater than 8.2. Figure 5 very clearly shows the mixing of river and sea water progressing down the estuary, with the cold sea water cooling off the warm estuary water below South Bend, where the proportion of sea water is high. (Above South Bend, the heat from the sun balanced the sea waters' cooling effect.) A uniform rise in pH downstream is shown.

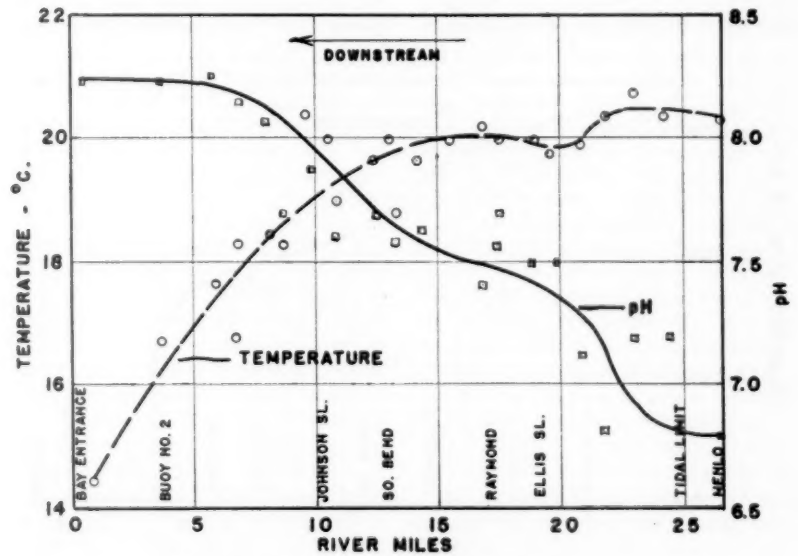

FIGURE 5.—Average temperature and pH values.

Chlorides

Chloride samples were collected under all tidal conditions up and down the estuary, there being no appreciable change in value in any one section with water depth. This uniform condition was experienced with low stream flows; however, during high stream flows in the Willapa River, it is possible that the fresh water will run out to sea over the top of the denser sea water. Figure 6 shows the average chloride values and illustrates the intrusion of sea water into the estuary and the relative proportions of fresh water and salt water present at any location; that is, the potential amount of dilution afforded.

Dissolved Oxygen

The Willapa River enters the upper end of the estuary saturated with dissolved oxygen and leaves the estuary nearly saturated, as shown in Figure 7. There was no appreciable difference in dissolved oxygen with depth. The maximum oxygen sag takes place in the vicinity of Raymond, the present source of the greatest pollution. The low average dissolved oxygen content obtained near Raymond was surprising (about 5.5 p.p.m.), as rough calculations indicated that raw sewage discharge from Raymond would produce less than half this depletion. The excessive oxygen depletion was attributed to decomposing wood and wood wastes, which are in abundance on the estuary bottom, shores, and floating in the water.

If a minimum dissolved oxygen standard of 5 p.p.m. is used, then it is apparent that no residual dissolved oxygen would be available in the vicinity of Raymond to provide for the oxidation of pulp mill wastes.

Theoretical Detention Times in Estuary

In long tidal estuaries the amount of net water movement seaward is determined by the volume of river flow into the upper end of the estuary. If river water was not entering the upper end of the estuary, there would, of course, be no residual or net water movement seaward.

A considerable amount of Willapa Bay water that is discharged into the Pacific Ocean on an ebbing tide is re-

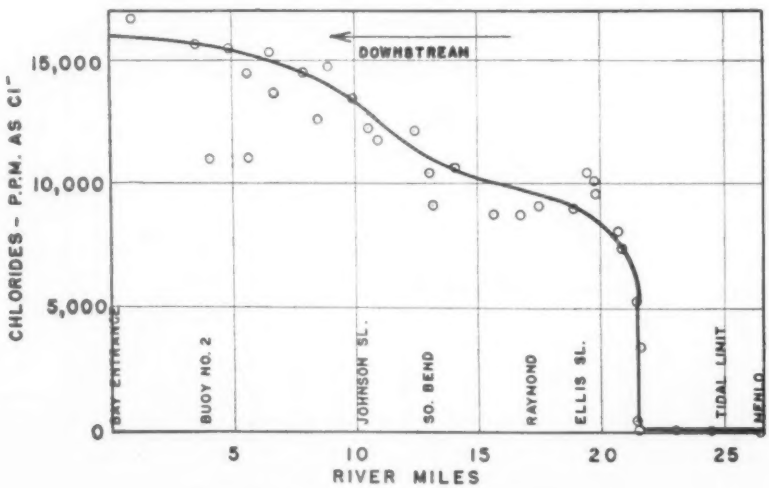

FIGURE 6.—Average chloride concentrations.

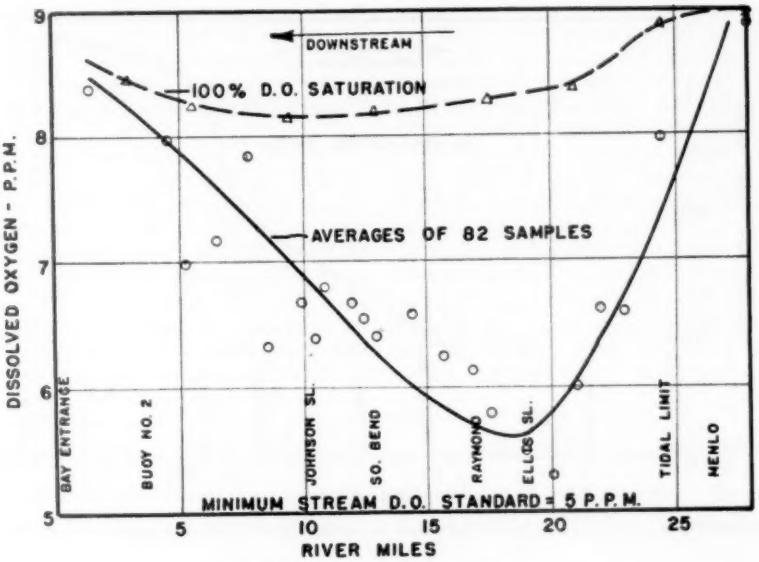

FIGURE 7.—Dissolved oxygen sag.

turned on a flooding tide, as evidenced by the normal chloride content of 16,000 p.p.m. near the mouth of the bay. Pacific Ocean water in this area has a normal chloride content of around 17,500 p.p.m., as reported by Erickson and Townsend (3). Current tables indicate no continuous pronounced ocean current past the bay entrance that would carry away all waters discharged on an ebb tide.

In ascertaining the desirability of discharging wastes from a pulp mill at some point on the estuary, it was necessary to know what dilution would be provided the wastes at that point and how long that waste-laden estuary water would oscillate back and forth with the tidal cycles before finally being discharged into large volumes of diluting water in Willapa Bay beyond buoy No. 2. Figure 8 is a plot of Table I, which lists the successive steps in computing the theoretical time of detention in the estuary.

The time of detention was computed by taking, arbitrarily, segments of the estuary each about 2 mi. long. The average chloride content of each segment was multiplied by its volume and the resulting product was added to the summation of the downstream products of chloride and volume. This summation was divided by the total downstream volume, with the quotient representing the average chloride content of the entire estuary below a given location. Using a normal chloride content of 16,000 p.p.m. in the sea water and 20 p.p.m. in the fresh river water, the volume of fresh water present in the section under consideration is computed by proportion, as shown in the sample calculations (footnote, Table I). During the period of survey, the Willapa River had an average flow of about 50 c.f.s. All other sources of fresh water added to the estuary, such as the South Fork of the Willapa, sewage, ground water, etc., were estimated as 25 c.f.s. and, for practicability, were all considered to be tributary to the estuary at

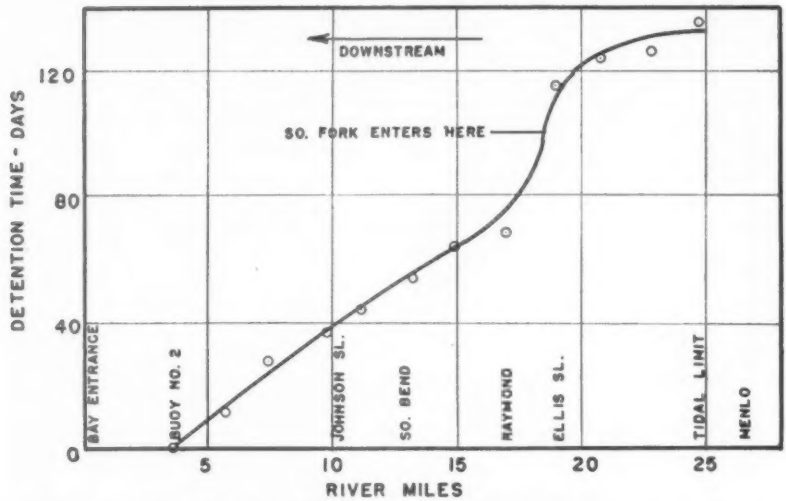

FIGURE 8.—Computed time of detention in estuary from point of release to buoy No. 2.

TABLE I.—Computation of Waste Detention Time in Willapa River Estuary [1]

Estuary Segments (mi.)	Av. Chlorides, Fig. 6 (p.p.m.)	Segment Volume (cu. ft. $\times 10^7$)	Col. 2 $\times$ Col. 3 ($\times 10^{11}$)	Summation Col. 4 ($\times 10^{11}$)	Volume Downstream (cu. ft. $\times 10^7$)	Av. Cl Values Downstream (p.p.m.)	Fresh Water Added (c.f.s.)	Volume Fresh Water (cu. ft. $\times 10^6$)	Fresh Water Added Daily (cu. ft. $\times 10^6$)	Theo. Time of Deten. (days)
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11
3.6– 5.5	15,300	172.6	2.64	2.64	172.6	15,300	75	81.6	6.51	12.5
5.5– 7.4	14,800	125.2	1.85	4.49	297.8	15,000	75	187.5	6.51	28.7
7.4– 9.8	13,800	51.6	0.713	5.203	349.5	14,900	75	243.5	6.51	37.5
9.8–11.3	12,700	24.5	0.312	5.515	374.0	14,800	75	282.0	6.51	43.3
11.3–13.1	11,550	15.7	0.181	5.696	389.7	14,600	75	350.0	6.51	53.8
13.1–15.0	10,400	15.6	0.162	5.858	405.3	14,400	75	413.0	6.51	63.5
15.0–16.9	9,500	13.7	0.130	5.988	419.0	14,300	75	437.0	6.51	67.5
16.9–19.0	9,075	11.8	0.1075	6.096	430.8	14,100	50	506.0	4.32	117
19.0–20.8	8,540	6.2	0.0527	6.149	437.0	14,050	50	530.0	4.32	123
20.8–22.8	3,500	4.1	0.0142	6.163	441.0	14,000	50	544.0	4.32	126
22.8–24.9	20	1.5	0.0000	6.163	442.5	13,900	50	588.0	4.32	136

[1] Willapa River average flow July 6 to August 14, 1950 = 50.13 c.f.s. Other fresh water sources to estuary above mile 16.8 taken as 25 c.f.s. Sea water and fresh water chlorides taken as 16,000 and 20 p.p.m. at mile 3.6 and 24.9, respectively.

[2] Sample calculation: Let volume fresh water = X. Then

$$\frac{X(20) + (1{,}726{,}000{,}000 - X)16{,}000}{1{,}726{,}000{,}000} = 15{,}300 \text{ p.p.m. Cl}$$

X = 81,600,000 cu. ft. of fresh water.

$$\text{Time in estuary} = \frac{81{,}600{,}000}{6{,}510{,}000} = 12.5 \text{ days.}$$

Raymond. If the volume of fresh water in a section of the estuary is divided by the daily rate of fresh water addition, the quotient will represent the detention period of that portion of water in the estuary.

Figure 8 shows, then, that if a kraft-type pulp mill discharges into the estuary at Ellis Slough (one of the sites under consideration), 116 days would be required for the waste water to reach large-scale dilution past buoy No. 2. On the same basis, 38 days would be required if discharged at Johnson Slough. A waste discharged into the estuary is, thus, obviously not carried to sea on each ebbing tide, but remains in the estuary for a considerable time, exerting perhaps its total oxygen demand. This, of course, is assuming that the river flows do not exceed the values used in the computations. Increased flows due to rains will shorten the time in the estuary; however, these values indicate that most of the waste material discharged during low flows remains in the estuary for the entire low-flow period.

If the pulp mill were to obtain its entire process water from another watershed and discharge about 25 c.f.s. into the Willapa River estuary, then the time of detention would be reduced from 25 to 35 per cent. This factor would be compensated for, however, by the fact that the survey period did not extend through the entire dry season. If it had, the average river flow would have been 35 to 40 c.f.s., rather than 50 c.f.s.

Dissolved Oxygen Depletion

One of the effects of waste discharge from a pulp mill is the oxygen depletion in the receiving waters. Figure 9 and Table II represent an attempt to show theoretically what oxygen depletion might be expected in the Willapa

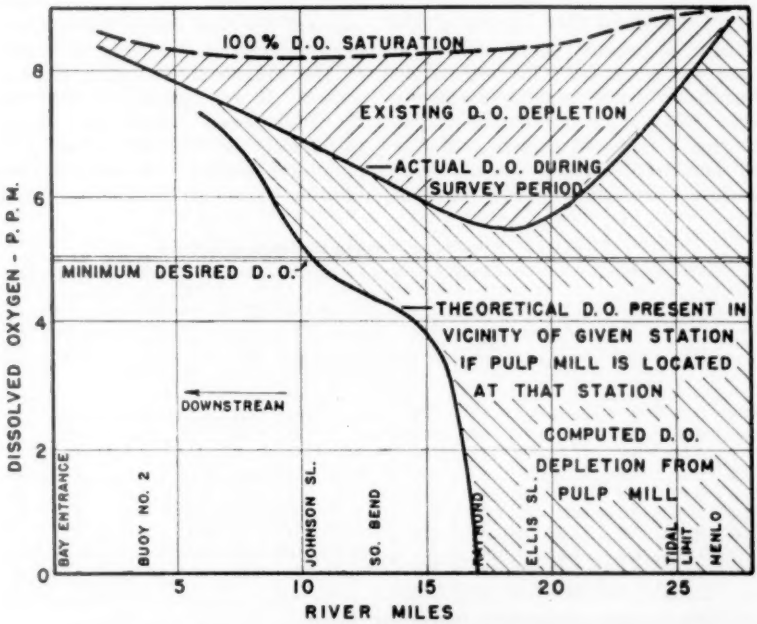

FIGURE 9.—Computed pulp mill effect on estuarial dissolved oxygen.

River estuary if a hypothetical kraft-type pulp mill were discharging at any given point along the estuary. Average kraft mill waste water characteristics were taken from Wisconsin studies reported by Warrick (9), although they were reduced in magnitude for this study because of improved operational characteristics and waste prevention measures that would be expected at the mill proposed for the Willapa River area.

The hypothetical kraft mill waste was assumed to have an average 5-day B.O.D. of 60 p.p.m., with the significant oxygen demand being satisfied in 20 days according to the unimolecular theory. The capacity of the mill as proposed will be 235 tons of pulp per day. A waste volume of 65,000 gal. per ton of pulp or 15.3 m.g.d., is assumed. Estuary segments and volumes affected during a 20-day period for discharge of waste at given points was approximated from Figures 8 and 3. Assuming a waste D.O. content of 0.0 p.p.m., the initial D.O. content of the mixture of estuary water and mill waste was computed. Re-oxygenation from the atmosphere during this 20-day period was computed from the oxygen absorption tables of Imhoff and Fair (8) and from estuary surface areas previously determined. After computing the net oxygen depletion, the remaining oxygen was computed and plotted in Figure 9, which shows that if a minimum D.O. value of 5.0 p.p.m. is to be maintained, then the mill waste should be discharged no further upstream than Johnson Slough at river mile 10.1.

Toxicity Concentrations

Kraft pulp mill liquor contains compounds that are toxic to aquatic life. Minimum lethal concentrations on minnows and fish food for some of these waste components are 0.5 p.p.m. for sodium sulfhydrate and methyl mercaptan and 1.0 p.p.m. for hydrogen sulfide and resin acids, according to Van Horn, Anderson, and Katz (10). In order to study the possible effects of the mill wastes it was assumed that the waste water would contain 5 p.p.m. total of these toxic substances and that the toxic material would be lethal only for a period of 24 hr. These assumptions were made with the understanding that the proposed mill would have modern facilities for removal of most of the toxic material from the mill wastes. It was further assumed that the mill waste would be diffused throughout the full tidal prism at the point of discharge in the estuary. This diluting water was assumed to oscillate

TABLE II.—Hypothetical Oxygen Depletion in Estuary [1]

River Mile[2]	Av. Tidal Vel., Fig. 4 (m.p.h.)	Dist. Carried Up-stream (mi.)	Estuary Segments Affected in 20-day Per. (mi.)	Vol. of Segment (cu. ft. $\times 10^9$)	Init. D.O., Fig. 7 (p.p.m.)	Init. D.O. in Diluted Water (p.p.m.)	Surface Area Involved (acres)	Reoxygen. in 20 Days (lb. $\times 10^6$)	Oxygen Depletion in Segment		Oxygen Remaining (p.p.m.)	D.O. Saturation (%)
									(lb. $\times 10^6$)	(p.p.m.)		
20.8	0.35	2.2	24.5–18.4	12	5.9	4.4	132	1.03	1.23	16.4	0.0	0
18.9	0.60	3.7	21.7–18.2	12	5.6	4.2	135	1.05	1.21	16.2	0.0	0
17.1	0.65	4.0	17.8–15.3	19	5.8	4.8	150	1.17	1.09	9.1	0.0	0
15.2	0.75	4.6	16.9–12.7	35	6.0	5.4	353	1.91	0.35	1.6	3.8	46
13.3	0.75	4.6	15.5–11.1	42	6.3	5.7	378	1.89	0.37	1.4	4.3	52
11.4	0.70	4.3	13.3– 9.2	48	6.6	6.1	396	1.83	0.43	1.4	4.7	57
9.5	0.90	5.6	11.3– 7.5	65	6.9	6.5	578	1.85	0.41	1.0	5.5	67
7.6	1.00	6.2	9.2– 5.7	161	7.2	7.0	1,310	2.08	0.18	0.2	6.8	83
5.7	1.20	7.4	7.5– 3.9	237	7.5	7.4	2,220	2.22	0.04	0.03	7.4	89

[1] Assumptions do not correct for temperature changes.
[2] Willapa Bay entrance at mile 0.0.

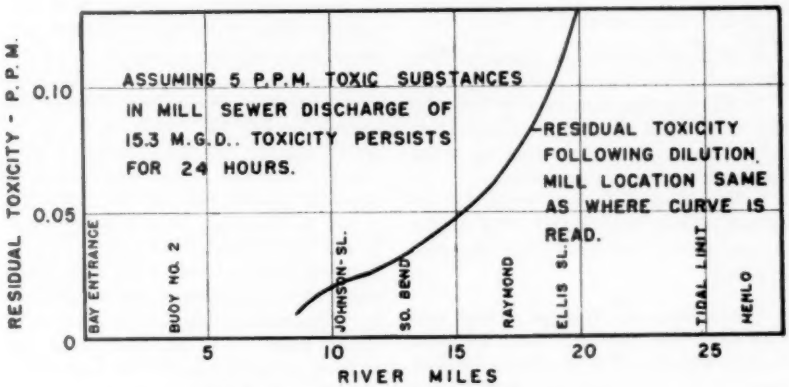

FIGURE 10.—Computed toxicity concentrations.

back and forth by the point of waste discharge for a period of one day. As shown in Figure 10, the final concentration of diluted waste in the estuary below Ellis Slough is well below the minimum lethal concentrations for minnows and fish food, if perfect mixing of waste and water were obtained.

No data are available on the minimum lethal concentrations for Pacific oysters (the kind grown in Willapa Bay) and other shellfish. It is desirable that such information be obtained, as it appears to be the principal missing link in these studies. In addition, however, studies should be conducted to substantiate the assumption that toxicity of kraft waste is dissipated within a 24-hr. period. (The pulp-producing company for whom this study was made expects to make such toxicity investigations in the near future.)

Conclusions and Recommendations

1. Waste water from a kraft-type pulp mill should be discharged in the Willapa River estuary no farther upstream than the vicinity of Johnson Slough. Insufficient dilution will cause a serious dissolved oxygen depletion if discharge is farther upstream.

2. If possible, storage of sufficient time to allow for the decomposition of toxic materials should be provided before the waste water is discharged to the estuary.

3. Waste water should be discharged continuously at a constant rate, rather than only on an ebbing tide. The oscillating tidal motion negates the value of an ebb-tide discharge. More mixing and dilution will result from a continuous discharge.

4. Discharge of waste water should be by diffuser pipe or other means so that the waste water is distributed evenly across the estuary rather than being concentrated at one point.

5. Sewage treatment should be provided in Raymond and South Bend to improve the bacteriological, aesthetic, and dissolved oxygen quality of the estuary water.

6. A study should be initiated to determine the toxic characteristics of diluted kraft mill waste water on the Pacific oyster and this study should include the effect of time and storage on toxicity.

Summary

A survey and study of the Willapa River estuarial area in Southwestern Washington State was made for the purpose of determining:

1. The feasibility of discharging waste water from a proposed kraft-type

pulp mill into the Willapa River estuary.

2. The most suitable point of discharge for this waste liquor.

3. The existing condition of the estuary as affected by raw discharge from two cities and by decomposing wood wastes from several sawmills.

4. The bacteriological condition of of the estuary and oyster beds at the mouth of the estuary. (Not reported herein.)

The section of Willapa River and Bay surveyed was 30.1 river miles in length, with the Willapa River estuary itself having a length of about 23 mi. at low water. Samples were collected during dry-weather conditions, which provided minimum steady stream flow conditions. Determinations were made for dissolved oxygen, chlorides, pH, temperature, coliform bacteria, and current movement. The Willapa River has a mean annual flow of 613 c.f.s., with minimum dry-weather flows in the summer of less than 30 c.f.s.

The discharge of raw sewage and the accumulation of wood wastes has reduced the dry-weather dissolved oxygen content to less than 6.0 p.p.m. in the vicinity of Raymond, leaving little remaining available oxygen for additional waste matter in this area if a minimum value of 5.0 p.p.m. is required.

Waste material discharged into the estuary 2 mi. above Raymond (a potential mill site) would, during the dry months, have an estimated detention period of 118 days in the estuary before discharge into a large volume of diluting sea water in Willapa Bay. Material discharged into the estuary at Raymond (another potential mill site) would be detained 75 days, at South Bend 53 days, and at Johnson Slough 38 days. Detention periods were calculated using river flow, estuary volumes, and chloride values.

Good mixing of fresh and salt water was evident in the estuary during the survey period with little variation in water quality or characteristics with depth. Average velocities, due mostly to tidal movement, varied from 1.3 m.p.h. in Willapa Bay to 0.25 m.p.h. in the upper end of the estuary.

Using assumed kraft-type mill waste water characteristics, it was determined by approximate calculation that waste water must be discharged into the estuary no farther upstream than Johnson Slough in order to maintain a minimum dissolved oxygen concentration of 5.0 p.p.m. The two contemplated pulp mill sites and point of waste water discharge would, if used, remove all available dissolved oxygen from estuarial waters. The residual toxicity of the waste water diluted in the estuary for any point of discharge below Ellis Slough appears to be negligible, unless it is found that the Pacific oyster is extremely sensitive to these waste substances, in which case storage for a period sufficient to cause the destruction of toxic compounds will be necessary.

Sewage treatment facilities should be provided in Raymond and South Bend to improve the dissolved oxygen and bacteriological condition during low river flows and to improve the appearance of the estuary.

Acknowledgments

The Pollution Control Commission Survey group consisted of the following: Gerald T. Orlob and Kenneth R. Jones, survey engineers; Donald R. Peterson, survey biologist; and Alfred T. Neale, field engineer.

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ATOMIC ENERGY CONFERENCE SCHEDULED

Designed to spread information on the facts and future of atomic energy, Michigan State College has announced a two-day conference, titled "Atomic Energy and the Future," on May 20–21, 1952. The program of which this conference is the opening phase is primarily to make information concerning atomic energy available to those who might be able to apply it in their special fields.

Emphasis in the conference is to be placed on possible uses of atomic energy in industry for power generation, including the personnel hazards, wastes treatment problems, etc.

Sponsors of the program are the college's Department of Mechanical Engineering and the Continuing Education Service. Cooperative endorsement has been obtained from the Dow Chemical Co. and the Detroit Edison Co. Participating experts have been invited from Massachusetts Institute of Technology, University of North Carolina, and AEC's Argonne National Laboratory, as well as Michigan State College's own staff.

Further information concerning the conference and the continuing program may be obtained from Professor Donald J. Renwick, Mechanical Engineering Dept., Michigan State College, East Lansing, Mich.

THE OPERATOR'S CORNER

CONDUCTED BY HERBERT P. ORLAND

1951 OPERATOR'S FORUM *

GEORGE E. SYMONS, *Leader*

Consultant and Technical Editor, Larchmont, N. Y.

Chlorine Conservation

Chairman Symons:—The Forum program lists four topics, selected with the idea that treatment plant operating problems change. It is the desire of operators to get the latest techniques and operation improvements, although sometimes they are forced into the improvements. One such instance is the matter of chlorination.

At the 1950 Federation Board of Control meeting in Washington, a special committee was appointed to study the problem of chlorination and chlorine supply. There had been several complaints of chlorine being unavailable to sewage treatment plants. The committee performed important services in the preparation and adoption of the National Production Authority's Order M31, which established controls over chlorine distribution and assures availability of the chemical to water and waste treatment plants. Conditions indicate that consumers face a difficult period for several years, during which chlorine production will not be adequate to meet the demands for all uses.

A factor in these developments has been the tendency of chlorine manufacturers to lose interest in the municipal field because there is a heavy demand in the chemical field for all the chlorine they produce, without any of the headaches involved in municipal purchasing practices.

Because chlorine and chlorine containers are in short supply, it behooves all operators to do something about saving chlorine or utilizing it more efficiently in chlorination of sewage, whatever the purpose of the chlorination may be.

Ralph A. Hoot, Superintendent of Sewage Treatment, Philadelphia, Pa. (formerly, Superintendent of Sewage Treatment, Fort Wayne, Ind.):—At Fort Wayne odor control was extremely important because of the local opposition to the location of the plant when it was built. All of the plant chlorination, which was for odor control only, was under automatic control. During the first year of operation it was discovered that satisfying about 70 per cent of the chlorine demand would eliminate most raw sewage odors. Consequently, the automatic chlorine control equipment was set to leave an unsatisfied demand of about 30 per cent. An article on this arrangement appeared in the July, 1949, issue of *Water & Sewage Works*, page 267.

The entire chlorination set-up at Fort Wayne (including two chlorinators, controllers, program timers, and all necessary accessories) cost $15,300, or approximately 1 per cent of the cost of the plant. In 8 years of oper-

* From transcript, 24th Annual Meeting, Federation of Sewage and Industrial Wastes Associations; St. Paul, Minn.; Oct. 8–11, 1951.

ation, $96,000 was spent for supplies and maintenance, of which total only $442 went into maintaining the chlorination equipment. Automatic chlorination control at Fort Wayne gave effective odor control and at the same time conserved chlorine by effective utilization of the dosages used.

Harry A. Faber, Research Chemist, The Chlorine Institute, New York, N.Y.:—There seems to be a pretty general conception that chlorination is a very simple process. That idea has resulted in more poor applications of chlorine than anything else, because chlorination isn't simple and the reason it isn't simple is that the results of chlorination are seldom evident, except in the case of odor control. Bacteriological tests or chemical tests are necessary to see whether or not chlorination is functioning effectively.

The only way to conserve chlorine, in general, is to understand the fundamentals of the chlorination process: what is to be done, whether or not it is being accomplished, and whether or not it is being accomplished as economically as possible. The best recommendation that I could make would be to read the Federation's new "Manual of Practice No. 4," which has been issued recently and which is a presentation of just about all the material there is on the chlorination of sewage and industrial wastes.

C. C. Larson, Chemist, Springfield (Ill.) Sanitary District:—We talk about conserving chlorine; but who is to judge whether or not we are wasting chlorine? For example, in the Springfield water system we carry a residual of 0.4 or 0.5 p.p.m. with good bacteriological results. In other places the water plant carries 2 full p.p.m. residual "just to be on the safe side." In a plant handling any volume of water the difference in consumption of chlorine between a residual of 0.4 and 2.0 p.p.m. amounts to a lot of chlorine.

Louis K. Ekstrand, Superintendent, North Shore Sanitary District, Waukegan, Ill.:—In water chlorination a standard residual of so many parts per million may be justified, but in sewage chlorination that doesn't always hold true. To meet the water standard for bathing beaches in the area, the North Shore Sanitary District plants must have nearly complete bacterial kill. The state authorities require an effluent residual of 0.5 p.p.m., but in one of the District plants we shoot for 3 p.p.m. Most of the eight installations are Imhoff units and even with 3 p.p.m. residual the kill is not always complete. On the other hand, a complete kill has resulted at times with a residual of 1 p.p.m. Also, we have found that there is such a thing as too long a detention time. We have found the best control for chlorine conservation to be residual tests at 1-hr. intervals. Despite what the manufacturers may claim, automatic control of chlorine dosage must be supplemented by manual control.

Chairman Symons:—Conservation can be accomplished by using the right amount of chlorine and holding the right residual. A second requirement, however, is to maintain the desired residual throughout the contact period, thus preventing over- or under-dosage. Local conditions make a difference in the approach to the problem. For example, at Buffalo, N.Y., bacterial kill is the principal criterion of operation, inasmuch as one-third of the Niagara River is available for dilution. In this case, it is only necessary to reduce the bacterial count to about 1,000 coliforms per milliliter. Buffalo practices chlorination before sedimentation. With this long contact period it is possible to reduce the coliform density with a low residual and have no residual in the plant effluent. Buffalo also has hourly control for determining chlorine demand and chlorine residual so that the chlorinators can be set to follow the demand and the flow variations.

Herbert O. Lord, Chief Engineer, Madison (Wis.) Metropolitan Sewer-

age District:—Several years ago we were using about three carloads of chlorine per year for odor control. This year no chlorine has been used for this purpose. One of the sources of the odors was the treatment plant, which employs trickling filters and activated sludge. By keeping a moderate dosage on the filters through the night the objectionable odor conditions have been eliminated.

Severe odors have been a problem at pumping stations in the city, particularly at one having a large wet well conducive to sludge deposition and decomposition. In three new pumping stations built recently, this condition has been overcome by the simple expedient of using small wet wells and providing each with a water trap. The trap is simply a depression at the end of the sewer with a wall coming down into the depression to a point below the sewer invert. The wet well and screen room is force ventilated, with the exhaust air being discharged to the sewer.

A. E. Griffin, Director of Technical Services, Wallace & Tiernan Co., Inc., Newark, N.J.:—The best way to conserve chlorine is to have a proper plant for sewage treatment and to operate it properly.

A second way to conserve chlorine is to know what the chlorine is being used for. Is it being used simply to kill odors? Is it being used to kill bacteria? If for the latter purpose, to what extent is the attempt being made to kill the bacteria? Is the desired result a simple percentage reduction, or a reduction to a standard number of bacteria remaining in the effluent? It makes all the difference in the world. Is chlorine being used to remove grease, or to improve plant operation, or to prevent bulking? Each of these uses has its own chlorine dosage. Some are based on chlorine residual, others are not.

A third factor in conserving chlorine is the question of chlorine residual. It has already been pointed out how it is necessary for one plant to maintain a residual of 3 p.p.m., whereas others only carry 0.3 p.p.m. That indicates a need for a better way of determining the chlorine residual in sewage. Arbitrary residual values, even with definitely stated contact periods, are not the complete answer; the orthotolidine test will not tell how many bacteria remain after chlorination.

On the matter of control, there is programmed control and flow control. In programmed control the chlorinator is set for three selected doses to be automatically applied during predetermined time intervals. That equipment has been in use for a number of years. Flow control follows the flow with a set dosage of chlorine. These controls tend to prevent under- or over-dosage, but do not compensate for demand variations.

Walter H. Brown, Jr., Sales Engineer, Builders-Providence, Inc., Providence, R. I.:—Automatically paced and program controlled machines have been developed to assist the operator in cutting down the time required to attend the machines and to conserve chlorine. The manufacturers of these machines are highly in favor of the effort to conserve chlorine; without conservation effort there just isn't going to be enough to go around.

In operation of the Cranston, R. I., sewage treatment plant, industrial wastes caused severe trouble. However, we found the application of chlorine to be a tremendous help in controlling plant operation.

Chairman Symons:—Up-sewer chlorination is another means of conserving chlorine. If the water supply has sulfates in it and the sewer line is long, hydrogen sulfide will develop. That takes more chlorine to satisfy its chlorine demand than does the sulfur when in the organic form. Up-stream addition of a sub-residual chlorine dosage prevents growth of sulfate-splitting bacteria, in turn preventing the formation of hydrogen sulfide, and thereby

reducing the amount of chlorine required at the treatment plant.

In Buffalo it was determined in advance of building the plant that upsewer chlorination was not necessary. That knowledge saved some $50,000, more than enough to pay for the operation of the experimental laboratory which made the discovery.

Mr. Faber:—There is also the situation of using chlorine to save something else. An excellent illustration of this condition is the Los Angeles County Sanitary District plant, where up-sewer chlorination to prevent septicity of the warm sewage increased the actual capacity of the new activated sludge plant four-fold. In other words, plant capacity was conserved by use of chlorine in the proper manner.

Meter Maintenance

Chairman Symons:—In many sewage treatment plants everything is measured by some metering device. And each of these devices has its operating difficulties and adverse conditions, so each needs maintenance. Just as an automobile should be maintained by periodical inspections, oil changes, etc., a meter and its recording, totaling, or registering device should be checked, oiled, cleaned, and maintained.

Leslie E. West, Chief Engineer, Joint Meeting, Orange, N.J.:—The trunk sewer system of the Joint Meeting serves 12 communities that pay for the cost of operation in proportion to the contributed flow. Therefore, quite a complex variety of meters is involved, with a good many being Venturi meters. When one has to certify the measurement of flow for purposes of payment, it is understandable that there should be a desire to be sure the meters are in good operating condition and recording accurately. Therefore, we have had some interesting maintenance problems on Venturi meters.

Except for those at the plant, the principal control meters have a capacity of about 60 m.g.d. Those operated by direct float connections are preferred to the mercury type. As part of the normal maintenance program, the charts of these meters are changed every Monday. At the same time the meter men bring each meter down to zero and then check the build-up again to the rate of flow indicated at the time they entered the building.

If the meter recovery is sluggish, the Venturi tube piezometer rings are flushed out under pressure, and often drained. It has been found that short circuiting of this cleaning water is an inherent deficiency in this type of equipment. Therefore, we often tap the rings to dislodge any sediment while they are being flushed.

Gauge glass connections also have been put on the outside of the float tubes so that the liquid levels can be checked physically. That, of course, is another way of confirming the accurate operation of the meters.

Mercury-type meters are rather complex. Therefore, we do not like to have our men take them apart. They have worked satisfactorily for two or three years, after which we have the manufacturer send in a man from the factory for a day or two to check them over. His certificate of accuracy for each meter is a welcome addition to the plant records.

John J. Wirts, Superintendent, Easterly Sewage Treatment Plant, Cleveland, Ohio:—Maintenance and repair of metering equipment requires a peculiar talent not generally prevalent among the workmen hired at most sewage treatment plants. In the term "metering equipment" I include any instrument, even a chlorinator.

Cleveland has some rather large plants by comparison with most, and has been able to spend more perhaps on maintenance than others could. We sent one of our men, a millwright, to an instrument manufacturer's factory to learn all about the machines even before they were put into operation. We

have found it very beneficial to have one man trained for that particular work and to keep the other men away from that type of equipment. In addition, to train a man in this manner raises his morale considerably and increases his pride in doing a better job.

Perhaps for the smaller plants some reciprocal arrangement could be worked out whereby one man would be trained on chlorinators and measuring devices so as to service that equipment in all plants in an area. The subject of metering is so important and technical that the average small plant superintendent doesn't have the time to get into all its phases. Also, it is generally beyond his budget means to have a factory representative service the equipment. However, he can usually find the funds necessary for such a cooperative scheme as has been suggested.

Mr. Brown:—About 1939 or 1940, several instrument manufacturers inaugurated the idea of a service contract, whereby a factory representative would visit the plants in an area periodically and service the equipment. World War II seriously interfered with that program, but most of the instrument manufacturers now are reinstituting it in some form.

The matter of servicing the small plants is of much concern. However, periodical trips through an area by skilled service men can reduce the cost of service contracts to the point where they become economical for the plants serviced. The response to this type of service is highly gratifying.

As regards flushing of the annular rings of Venturi tubes, at least two manufacturers are producing Venturi tubes without annular chambers for use in sludge measurement, but with accuracies so near those of tubes with the annular chamber that they are perfectly acceptable for sludge measurement. With just the one take-off at high- and low-pressure points in the tube and continuous backflushing, the passages are kept clear and the meter registers accurately over a much longer period than does the conventional tube with the annular ring and four or more ports. This type of tube without the annular ring is not recommended, however, for measurement of sewage.

Louis J. Fontenelli, Supervising Engineer, Rahway Valley Joint Meeting, Garwood, N.J.:—The costs of operating the Rahway Valley Joint Meeting are apportioned to each municipality on the basis of the contributed flow. Through many years of experience we have found that the simpler the device for recording, the less maintenance is required and the greater the accuracy.

Toward the second full year of recording flows from one municipality it was found that the plant electrical recording instrument was recording from 5 to 30 per cent error in the flow. That immediately created quite a problem, because the municipality had to be refunded money overcharged the previous year. The trouble was finally found to be due to the wearing of the cam in the transmitter, which gave an erroneous relation between the elevation at the weir and the totalizing instrument within the plant. At some of the smaller plants, with only one totalizing instrument, a careful check should be made of the zero point of the weir and the instrument should be carefully calibrated in use. The check is a simple matter and well worthwhile to ensure accurate recording.

Because of the necessity for continuous accurate recording of flows, we changed from a complicated electrical transmitting instrument to a conventional float instrument operated from a stilling well and having continuous paper recording. The recording sheet is changed twice a month and the flow calculated from planimetered areas.

M. L. Wickersheim, Superintendent, Sewage Treatment Plant, Estherville, Iowa:—The flow at my plant averages about 2.25 m.g.d., which is measured by one meter. It has been found that the

operators are careless and do damage the instrument; for instance, I recently arrived at work one morning to find that the cleanup man had torn out all the instrument cables in his cleaning activities. How he did it is not known, but it took several hours to reconnect them and recalibrate the instrument.

Mr. Wirts:—The following incident might be helpful for those who base any rates on metered flow: In Cleveland a 6-ft. diameter tunnel with a large Venturi meter has been operating for 20 years on settled sewage. An examination of that tunnel revealed a deposit of soft grease-like material probably 5 in. thick on the tapered inlet casting of the Venturi meter. Where the velocity increased to provide the differential, the coating tapered down to almost zero thickness at the throat.

Extreme care should be exercised about being too positive concerning metered flows. The Venturi meter has done some marvelous work on water and the guarantees of accuracy may be valid with that medium, but it doesn't necessarily follow that the accuracy will hold after a period of sewage measurement service. We have tried to anticipate that condition. By checking back to zero as we do, by flushing, and by checking against water columns, we get a fair picture of any variations. Even then, we do not become too disturbed when the results are not exactly what we think they should be.

In some cases there may be two very large Venturi meters that can be checked against four smaller meters, the sum of the four theoretically equalling any portion or all of the flow of the two mains. The comparative results may not always check, probably due to spasmodic sloughing of material adhering to the inner surfaces.

Any designer of a Venturi tube prides himself on the extreme accuracy of his device, an accuracy dependent on the length and diameter of the throat, the angle of approach, and the discharge angle. Certainly a change of 4 or 5 in. in the inlet diameter will result in significant error.

W. W. Mathews, Superintendent, Gary (Ind.) Sanitary District:—Do you think it advisable to set a Venturi meter in sewage practice in a vertical rather than a horizontal plane?

Mr. Wirts:—I see no reason why it is absolutely essential to use the horizontal plane. Also, it is known that the longer the approach to the meter, the smoother and better the flow is, and the more accurate the measurement. Those things have to be looked at in a practical way. Under the circumstances, using sewage, sludge, excess sludge, or return sludge, the vertical position for economy is well taken.

Chairman Symons:—I haven't had experience with a Venturi changing its diameter. However, during flow studies it was found that the flow characteristics of one of the Buffalo, N.Y., interceptors changed from summer to winter. The change was due to a variation of 3 in. in the sewer diameter as grease collected during the winter and melted off in summer. The effect on the Venturi described by Mr. Wirts would depend on the angle of approach in the inlet, the change in roughness, and the thickness of the coating. These factors may or may not be compensating.

Sol Seid, Supervisor, Department of Public Works, New Brunswick, N.J.:—In the central section of New Jersey there are about 25 plants, of which 3 are large ones. Most of the others are small, and with their limited budgets are staffed only by one operator and a laborer or two. About five years ago there was set up a committee upon which all the plants could call. This "good neighbor" program has proved helpful to almost everyone involved.

An item of interest concerns a trick used by our maintenance men with flow meters at two pumping stations. Dur-

ing certain periods of the year, particularly in wet or cold weather, the meter charts wrinkled so badly that flow records were unobtainable. This condition has been remedied by putting louvres atop the wooden houses and air inlet holes in the doors. In really wet weather the door of the meter is opened and a 250-watt bulb is inserted for drying purposes. The results are amazing.

Frank L. Flood, Partner, Metcalf & Eddy, Boston, Mass.:—The question of coating on the interior of Venturi meters is of considerable interest. One particular case that has come to my attention is where the sewage flow from Peabody, Mass., enters the South Essex sewer system. The Venturi meter at that point handles a considerable amount of waste including lime and is, therefore, subject to continuous accumulation of a deposit on the interior. In that case it is essential to have a by-pass around the Venturi meter so it may be taken out of service and cleaned periodically.

There is also a question about sludge meters. It is known that sludge lines accumulate a serious deposit in the pipe and that the deposit must extend through the Venturi meter. It would appear essential to have a by-pass on the meter, or in larger plants to put in duplicate lines. That raises the further question of how to clean these lines. In many plants provision is being made to simplify passage of a "go-devil" through the lines periodically, thus reducing the problem to the meter itself.

Chairman Symons:—At Buffalo, grease in the sludge lines is removed by melting it out with steam. This practice has caused the cast-iron pipeline to expand and break the joints. Consequently, thought is being given to replacing the cast-iron sludge lines with steel pipe. The "go-devil" didn't work out too well. In fact, the grease accumulations cut down the pipeline capacity so badly that the pumps wouldn't handle the extreme pressures involved.

Robert D. Bargman, Assistant Chief Engineer, Hyperion Activated Sludge Plant, Los Angeles, Calif.:—We have found it necessary to clean raw sludge lines after about 8 or 9 months of operation. We simply bought a good "go-devil," inserted it in the line, and pumped it through. The flushing operation must be done with high pressure, which is available all along our raw sludge line. The "go-devil" worked satisfactorily, the line being cleaned and the pressure restored to normal in some 8 to 10 hr.

Chairman Symons:—Was there any deposition in the meters in that line?

Mr. Bargman:—A section of the raw sludge line adjacent to the meter was removed. Although the throat section was clean, there was build-up close to the meter. However, cleaning the approach was simply a hand job. Nevertheless, a difference is noticed in the raw sludge meter before and after such a cleaning.

N. S. Bubbis, General Manager, Greater Winnipeg (Man.) Sanitary District:—Has anyone present had experience with the orifice type of meter in sewage lines?

Mr. Brown:—We have had requests for the orifice meter for use on sewage and sludge lines. Frankly, our engineering department does not approve of this use, as any sharp-edged orifice or weir is very susceptible to clogging or to having material hang on it.

Marvin O. Kruse, Kruse Engineering Service, Spencer, Iowa:—We have installed a number of Parshall flumes in sizes from 250,000 to 600,000 g.p.d. and all have worked successfully. The Parshall flume is not quite as accurate as the Venturi meter, but it can be more easily maintained. Usually it is installed right in the influent channel of the plant and at such a place that the sewage flowing through it can be observed. Then if there is any clog-

ging or tendency to clog the operator can easily keep it clean.

The recording device on a Parshall flume is simply a stilling well and float arrangement to measure the differential in head between the entrance and throat levels in the flume. As a matter of checking, the Parshall flume readings should be checked against weir readings occasionally, because hard scraping during cleaning of the flume is likely to change its characteristics.

Henry Van Der Vliet, Superintendent, Joint Meeting Sewage Treatment Plant, Rutherford, N.J.:—If there is any appreciable grease in the sewage, it will affect the meter readings of a Parshall flume, probably because of interference with float operation. We clean our float wells and flumes every week.

John F. Laboon, Chief Engineer, Allegheny County Sanitary Authority, Pittsburgh, Pa.:—A very simple way of correcting the difficulties arising from grease accumulation and wear of concrete in Parshall flumes, as well as providing an accurate means of proportioning the control sections, is to use a welded steel section encased in concrete.

Increasing Effectiveness of Grit Removal and Sludge Dewatering

Chairman Symons:—The next subject is that of improving plant processes, particularly grit removal. Grit comes primarily from combined sewer operation, although there are a number of sewage treatment plants that do not have combined sewers, but should have grit chambers.

Kerwin L. Mick, Superintendent and Chief Engineer, Minneapolis-St. Paul (Minn.) Sanitary District:—A grit chamber is certainly essential in a combined sewer system. During normal dry weather or on an average yearly flow basis, we get between 4 and 5 cu. ft. of grit per m.g. of sewage. During rainy summers, such as 1951, when we had a record high rainfall since 1942, the grit more than doubles and we average about 10 cu. ft. per m.g. We've had some trouble in removing that grit at times, due to the fact that unless the grit chambers are carefully operated it is very easy to flush some of the grit into the settling tanks and thus cause plenty of trouble.

During so-called dry-weather periods the grit chamber velocity is allowed to rise considerably (held between 1.0 and 1.4 ft. per sec.) However, as soon as the meter charts indicate that a storm has started in the tributary area more chambers are thrown in and the velocity is cut down to between 0.6 and 0.7 ft. per sec. in an effort to keep the fine grit from getting through to the plant.

At times some of the fine sand will get flushed through. In fact, on one occasion one of our settling tanks was loaded down to the point where one of the cross collector brackets was actually torn off the concrete wall. When we dewatered that tank we found about 5 ft. of sand in the cross-collecting channel.

William S. Bloss, Sales Engineer, Worthington Pump and Machinery Corp., Buffalo, N.Y.:—What happens to the organic content of the grit when the grit channel velocity is reduced from 1.4 to 0.6 ft. per sec.?

Mr. Mick:—On our average yearly flow and grit removal, we seldom exceed 10 per cent in the grit as removed. In this case there is a washing action by the sewage as the grit goes up the inclined screw conveyors, so that the organic content averages 10 per cent. With heavy rains that figure goes even lower. With more street wash we get a cleaner grit; that is, the organic content is about 5 per cent. In reducing from a velocity of 1.0 or 1.4 ft. per sec. down to 0.6 ft. per sec. (as is done during storms), we come out with a cleaner grit than at the higher velocity.

Charles H. Young, Division Engineer, State Dept. of Health, Harris-

burg, Pa.:—When air flocculation is used doesn't it tend to wash out the organic material and leave a lot of fine grit?

Mr. Mick:—That is an interesting point. We wondered where some of the sand came from in our flocculators at times. When we were using flocculation and a storm came up, we loaded the flocculators down with grit; it is easy to flush the sand through and load up the flocculator, which is the first tank it would enter. However, we did not feel that separation by aeration was the explanation, because no separation was apparent during normal dry-weather operation of the flocculators.

Chairman Symons:—In a study made of the composition of grit during dry-weather operation, we listed the various things it contained to determine why it had a 50 per cent organic content. Among the most numerous items were beans, peas, corn, barley, angleworms, and spaghetti.

Mr. Van Der Vliet:—I had 12 ft. of grit to remove from a digester, but the material couldn't be taken out by jetting and pumping because it was all matted with hair. The material just wouldn't go through a pump; it had to be hoisted out through the digester cover in buckets. Although we have a grit collector and a separate sewer system, we still had 12 ft. of sand in the digester.

W. D. Hatfield, Superintendent, Sewage Treatment Plant, Decatur, Ill.:—The old grit chambers at the Decatur plant were of the manual control type, about 90 ft. long by 8 and 10 ft. wide. For many years we shoveled out the grit, which included paunch manure deposited at the outlet end of the chambers. The grit removed from the first two-thirds of the chambers was clean and was used to sand the sludge drying beds over the years; it had to be pretty good grit to be suitable for that purpose.

There were large openings in the bottom of the tank so the cleaning operation was simply one of dewatering a unit and shoveling the sludge through the openings into cars below. This was facilitated by the difference in levels, which permitted running a dump car under the cleaning holes. Nevertheless, grit chamber cleaning was the most disagreeable job around the plant, because of the large quantity of paunch manure involved, with the attendant odors.

Some three or four years ago mechanical grit removal equipment was installed. That equipment has been operating satisfactorily, producing a good clean grit. However, we have found that there are many classes of grit and that the handling of the grit differs widely with the time of the year. At certain times of the year the grit is rather clean, granular, coarse material that elevates easily and is entirely suitable for use on the sludge beds. The grit is washed automatically as it is elevated through the sewage for removal by truck. Washing also can be accomplished by a water jet agitator.

In autumn, of course, leaves present a problem. They get water-soaked, settle, and it is difficult for the grit to flow to the elevating devices. The material has to be pushed into the elevators. There are other times, in the spring, when the sticks and leaves that have fallen and gotten ground up to a rather mushy consistency during the winter—but still will settle—prevent the grit from flowing naturally to the elevators. This type of material also has to be pushed along to the elevators. The plant foreman has five or six classifications of grit, based almost entirely on how well it will flow to the elevator sump. There is no difficulty with the scraping mechanism, but different methods are necessary to get the grit to rise in the elevators.

From investigation of the causes of shear-pin breakage, we found that only a very fine gritty material gets to the outlet end of our grit chamber; a

material so fine it is almost at the activated carbon stage. No trouble has been experienced in the Imhoff tanks with fine grit.

We used to talk about 1 ft. per sec. as a grit chamber velocity. Since the grit removal mechanisms have been installed it's a little hard to say what the velocity is, because of the motion of the mechanism. Nevertheless, I would guess that the velocity in our chambers now is about 0.33 ft. per sec., with much better results than at the higher velocity. In other words, with mechanical grit removal we are using three grit channels all the time, whereas with hand removal only one or two were in use at any one time.

Mr. Flood:—Aerated grit chambers offer an excellent method of improving grit removal. From such observations as I've been able to make in the operations of the new aerated grit chamber at Columbus, Ohio, it appears that almost any fineness of grit desired can be removed by regulation of the air throughout the length of the grit tanks. I have been at that plant several times and have been impressed both by the quality of the grit and the fineness of it in the latter part of the chamber. I wonder if any operators have had experience with an aerated grit chamber. Air has been used in the past to stir up the grit and to remove volatiles, but the type of grit chamber referred to does not operate in that manner. It is a type of tank in which the diffuser tubes are suspended in one side of the tank, leaving a hopper or some space beneath for the collection of grit. Some plants using pre-aeration have experienced this accumulation beneath the tubes.

I expect the development of aerated grit chambers originated from the trouble with pre-aeration tanks. No doubt in the future where pre-aeration is used and where the tubes are suspended, it will be necessary to have some type of grit removal in conjunction with such tanks.

Carl B. Carpenter, Superintendent, Hammond (Ind.) Sanitary District:—I've had experience the past 10 years of operating a plant involving the combined use of air for pre-aeration and grit washing and removal. The two parallel units in our case, however, use diffuser plates. We've not experienced any difficulties of carry-over of grit to the digesters and the grit has been very clean. The arrangement provides for sweeping the grit, as separated from the raw sewage, into hoppers at the base of small low-head air lifts; lifting it into a header; and directing the grit into a classifier arranged for return of organic material to the raw sewage.

John S. Hess, Superintendent, Sewage Treatment Works, Fremont, Ohio:—Operation of a separate sanitary sewer system never gave me much trouble with grit. However, recent combined system operation has given me trouble. As Dr. Hatfield says, probably the 1 ft. per sec. rate should be discarded completely, now that such excellent washing mechanisms are available.

The fine silt resulting from combined operation (practically colloidal size) has given us the most trouble. In fact, it was discovered that within the annular trough outside the weir of the primary tank there was a heavy deposition of silt. Possibly de-ionizing of the colloidal particles by some means or other is causing this deposition—at a point where you would normally suspect that the detention period of the primary tank would have removed all that sort of thing. Something is keeping these particles dispersed until the sewage drops over the weir.

I wonder if there isn't another purpose in having aeration in a grit chamber; something to remove the fine particles that get in with combined sewer operation, but not in sanitary operation. In other words, pre-aeration may accomplish de-ionization of the fine particles of cinders and other grits caught by catch basins.

Mr. Larson:—If grit is not taken out in the grit chamber, it will accumulate in the digester. Mention has been made of cleaning digesters because of grit accumulation. I wonder why. We have seven digesters in the Springfield, Ill., plant, none of which is equipped with stirring mechanisms. We tried cleaning them at first. Then we came to the conclusion that if you let them alone, you're just as well off. The grit in our digestors forms a "doughnut" on the sloping hopper bottom and adopts an angle of repose that is about the same at all times. If the "doughnut" is removed, during the first few weeks new grit will accumulate on this slope, and very shortly you have the same condition that you started with. So we stopped worrying about cleaning the digesters. We figure that we lose that much of the effective volume of the digester and we might as well face it.

W. A. Sperry, Superintendent, Aurora (Ill.) Sanitary District:—That might be the case for a digester without stirring mechanism. With stirrers of the plow type, however, the grit can be kept moved out of the digester, even if it does get past the grit chamber.

Mr. Matthews:—From 8 to 10 cu. ft. of grit per m.g. of sewage are removed at Gary, Ind.; at peak loads the grit amounts to as much as 3.3 cu. yd. per m.g. With that sand volume, some carries over to the primary digester in the sludge, but very little carries over to the secondary digester.

In the primary digester (90-ft. diameter and 20-ft. sidewall depth) we have, on draining, found 8 ft. of sludge mixed with fine sand. Fortunately, it could be moved by flushing and pumping with raw sludge pumps. Also we have never had a sludge line to the beds clog with sand. We clean out the grit accumulation from the digester as regularly as possible, to utilize the total capacity of the digesters. With paddle agitators at the bottom of a rotating shaft we can keep the tank bottom fairly clear unless the agitators are out of service.

Mr. Bubbis:—Grit removal is definitely tied up with combined sewer operation. The Winnipeg system is of the combined type, so we also have the problem.

The Winnipeg Street Department finds chemicals of little use on the snow and ice because of the extreme cold. Therefore, several thousand tons of cinders and sand are deposited on the sidewalks and roads during the winter. Come spring, that material presents a problem, as the Street Cleaning Department has difficulty in cleaning the streets until they are dry and by that time a good deal of the cinders and sand has gone down the sewer. Some, of course, is stopped by the catch basins, but most eventually reaches the plant. The detritor unit at the plant normally does a good job, but a second unit is needed and is being installed.

In the spring it has been necessary on occasion to close the detritor down and shovel the cinders out of it because the mechanical unit couldn't handle it. In addition, there is another problem. Some of the silts arriving at the plant are so fine that they carry out of the detritor and are deposited in the digesters. It is extremely difficult to filter sludge containing any appreciable quantity of silt. For instance, after the 1950 flood there was so much fine silt carried over that we couldn't filter for about four months. The only way to get a cake to form at all was by mixing sawdust with the sludge. What with the bottom deposits and a scum layer that at times gets to be 8 ft. thick, the digesters have to be cleaned or there is no effective volume left.

As regards pre-aeration for grit removal, the only question I have is how to insert such units in existing plants.

Mr. Fontenelli:—Having just cleaned out a primary digestion tank, I can agree that there is a maximum point beyond which there is no grit build-up

on a digester bottom. If it becomes necessary to clean a digester, however, there are a few points worth considering. The first is means of access to get at the material, be it bottom deposits or scum. The second is a means of pumping hair balls and similar debris from the digester sump, by a positive displacement pump connecting to the sump by a pipeline. The third is a permanent pipeline to a lagoon or other storage unit for facilitating the digester emptying process.

Gordon L. Burt, Superintendent of Sewage Treatment, Portland, Ore.:—The new Portland sewage treatment plant, which serves a combined sewer system in an area of almost constant rainfall, comprises grit removal, measurement by large concrete Venturi tubes, primary settling, and separate sludge digestion. No grit has shown up in the grit channels, which are of conventional design, but about 2 ft. of fine silt has deposited in the Venturi tubes. This silt is being sluiced into the settling tanks, then moved by sewage ejectors to the digesters, where it no doubt will present an interesting problem in removal.

Despite a wonderful grit removal installation consisting of screw conveyors, elevators, etc., we have not yet had any grit—only the fine silt. With this problem, we are especially aware that it will be increasingly important to provide sufficient facilities in our digesters to remove the accumulated material when necessary.

Alvin A. Appel, Superintendent, Sewer Maintenance Division, Bureau of Sanitation, Department of Public Works, Los Angeles, Calif.:—At Los Angeles we have had few problems as far as grit is concerned. However, I wonder what effect increased use of household garbage grinders will have, particularly from the settling of coffee grounds, eggshells, etc., in sewers with flat grades.

There is one point that might be of interest. We have 31 pumping plants, some with quite large wet wells. Recently, an operator of an oil refinery became careless, permitting crude oil to enter the sewer and so get to our pumping plant. Crude oil floated 2 ft. thick on the wet well surface. That presented quite a problem for removal. Investigation finally turned up a vacuum pump, which is the heart of the vacuum unit developed to handle such situations. Briefly, the unit consists of a tank and a vacuum pump mounted on a truck chassis and suitably valved. The operator simply has to lower the suction hose into the well and open the valves. We also have used the unit for cleaning out all types of clarifiers whose material would be hard to remove in any other manner.

Operation of Combined Sewers

Chairman Symons:—The discussion so far has been on the effect of combined sewer operation, because that is what grit largely is. Now, however, we will take up the cause itself; that is, combined sewer operation.

Mr. Mick:—By way of introducing this subject for discussion, there are more than 1,600 mi. of sewers tributary to the Minneapolis-St. Paul plant. They are practically all combined; although Minneapolis has constructed 212 mi. of separate storm sewers since the plant started operation, probably between 80 and 90 per cent of our system is still combined.

The size of the intercepting sewers was based on all future extensions being built on a separate plan. The designers did not build an interceptor system large enough for the two cities to continue on a combined system indefinitely for all their new areas. That's why they are beginning to build some storm sewers now.

Before the plant could go into operation, 52 mi. of interceptors had to be built along both banks of the river to intercept some 75 old outlets into the river along the 20-mi. stretch through the Twin Cities. Where those inter-

ceptors join with the old outlets they are provided with regulators so that in times of heavy storm the excess storm water overflows directly to the river. The interceptor system was designed on the basis of taking rainfalls up to 0.04 in. per hour without overflowing to the river. Rainfalls of that intensity are only exceeded about 1.7 per cent of the time, so that actually slightly over 1 per cent of the total sewage flow overflows to the river by reason of having the combined system.

Based on our expected conditions, the designers allotted 44 per cent of the interceptor capacity to storm water, only 22 per cent to the domestic sewage alone, another 17 per cent to the industrial waste, and 17 per cent to infiltration. I believe that industrial waste figure is approximately right. Figuring on a strength basis, about 25 to 30 per cent of the plant load is due to industrial waste, which would correspond to somewhere near the 17 per cent on a volume basis.

Infiltration is one matter of interest. We've taken several infiltration measurements on our interceptor system. At times during the spring we by-pass all of the sewage out of the sewer system so that we can inspect the sewer and measure the infiltration. We have to be rather careful here with our quantity measurements, because we apportion the cost between the two cities on the basis of flow volume. Infiltration is a matter of concern because we correct for that in our measurements. We do that by placing a weir in the main interceptor coming into the plant, diverting all the sewage, and measuring the ground-water infiltration, which has run between 70,000 and 100,000 g.p.d. per mile of sewer. That value sounds high for ground-water infiltration, but we do not consider it excessive for the size of sewer. (It runs up to nearly 14 ft. in diameter and it is up to 200 ft. beneath the surface of the ground with a head of ground water as high as 40 ft. on the crown of the sewer at some points.) By walking through the interceptor at various times, we've determined that most of the infiltration enters at the original construction joints, although there have been a couple of leaks in the sewer itself. In 1944 we discovered one leak about 6 mi. above the plant coming through a sort of honeycomb section of the concrete in the invert, about 1 ft. thick and about 12 in. by 18 in. in section. That leak slowly increased, so in 1945 it amounted to 350 g.p.m. and we decided it should be repaired.

Another leak was discovered about 1.3 mi. above the plant in the spring of 1950. It's in the top of the sewer near the crown and is only leaking about 50 g.p.m., but we figure we will have to repair that too, probably in another year.

The sewer was inspected for erosion of concrete and disintegration; practically none has been found in the 13 years we've been using it, except a slight wear in the bottom 12 or 18 in. of the invert and the two leaks mentioned.

Deposits in the sewer are always a matter of interest. We found a few deposits, principally at points of curvature. On the inside of the curve there are deposits of boulders, rags, sand, and grit extending for 100 ft. or more along the curve, and just below the curve, up to a depth of 18 in. We cleaned one of those deposits out in 1946, then went back in there again two years later and found it had re-formed to the same depth. Inspecting it since that time, it does not seem to accumulate to any great extent, and it does not seem to interfere with the use of the sewer at the present time. There are also deposits from some of the St. Paul sections which were formerly creeks; there are a few old lake beds they also drained and naturally a fair amount of boulders wash into those connections and show up just below them.

Our sewer and the plant were both

designed hydraulically for a flow up to 615 m.g.d. and will take that quantity. Nevertheless, from the standpoint of treatment provided and troubles arising from grit and sand, we find that we can't take more than about 1.5 to 1.75 times our average flow without getting into trouble from flushing sand into the plant.

The grit problems involved have already been discussed. I might mention that we use an alignment chart for regulating the grit chamber velocities; our operators use that to control the grit chamber velocity by lining the number of chambers in service against the flow of the sewage so that they can determine what the flow velocity is.

We regard combined sewers as a fine means of freshening the sewage and cleaning out the system, especially during hot weather when the sludge is getting a little on the septic side and the alkalinity is going way up and making it difficult to filter. Then along comes a heavy rain, which freshens things up and lowers the alkalinity. But there are disadvantages of grit problems and overflows to the river at the regulators, which have a bad habit of becoming plugged with sticks and branches and sometimes staying open even after the storm is over, so that they have to be inspected following each storm.

Mr. Bubbis:—What safety precautions do you take in inspecting your interceptor sewer?

Mr. Mick:—The usual safety equipment is used; that is, the hydrogen sulfide and combustion indicators and the oxygen deficiency lamp, which are used before we enter a sewer. We have never found any dangerous atmosphere in the sewer system during inspection. There is usually a draft, probably through the old outlets, which are open at the river end where air can still enter.

TIPS AND QUIPS

Anti-Rust Paint

A new labor-saving anti-rust paint that is claimed to be applicable right over rust without wire-brushing, scraping, or sandblasting has appeared on the market. Available in black, aluminum, and clear, the product is known as "Rust-Cure" and is said to be suitable for both interior and exterior use on old or new metal. Upon application, either by brush or spray, it is said to penetrate through any existent rust layer and effectively seal the surface against further rust action.

The black and aluminum preparations are for use solely as a finish coat, whereas the clear compound can be painted over in any desired color. The aluminum is reputed to contain almost twice as much aluminum pigment as ordinary paints and to give an exceptionally brilliant finish coat. Further data are available from the manufacturers, The Monroe Company, Inc., 10703 Quebec Ave., Cleveland 6, Ohio.

Plastic Screw Anchor

Recently announced was a new type of screw anchor, which the manufacturer says can be used to secure nails or screws in practically any solid material, such as stone, brick, plaster, or cinder block. It is made of extruded Tenite plastic, which cold-flows into crevices of the hole to make a firmer grip. The device has additional advantages over metal anchors because it has unexcelled holding power, is corrosion-proof, and has exceptionally high impact strength according to the maker, Mastercraft Plastics Co., Inc., 95–32 150th St., Jamaica 4, N. Y.

Short Story

Scene I—Item in *New Yorker,* Nov. 3, 1951, p. 113, as follows:

Is there a professional friend or associate for whom it is always difficult to select a suitable nonpersonal Christmas gift? Here's one suggestion that will answer the problem for you—give him a copy of the 20 Year Index to *Sewage Works Journal.* —Adv. in the *Sewage Works Journal.*

It's as good as done.

Scene II—Clipping of the above arrives mysteriously in the morning mail from person or persons anonymous. Ye editor refreshes his memory by referring to THIS JOURNAL, 22, 11, 1481 (Nov., 1950).

Scene III—X-ray of envelope shows letter to *New Yorker* reading:

Gentlemen:

With reference to the item on page 113 of the November 3, 1951 number of *New Yorker,* we have not yet received the order for your copy of our "Twenty-Year Index." An order form is provided herewith for your convenience. Perhaps you may wish also to order some of our special publications.

The "plug" given our "Index" is greatly appreciated. We are anticipating a deluge of orders, as a high percentage of *New Yorker's* regular readers obviously are intensely interested in sewage and its various manifestations!

More from the Froth Fighters

Several recent communications contain many thought-provoking questions and a few helpful hints on coping with detergent frothing problems. Excerpts from a few of these letters (the correspondents are unidentified by their own requests) are as follows:

"What about detergent froth in activated sludge? It previously has been a subject of more or less facetious comment, but there comes a time when it can be an unmitigated nuisance.

"That time is when the ground at the aeration tank perimeter becomes supersaturated with 'foam juice,' which produces putrid odors out of all proportion to its volume. Has there been any serious consideration toward coping with this new dilemma in design of new plants? Or is such of sufficient importance to warrant bothering high-priced mental powers?

"Our evergreen planting is turning up its toes. In an attempt to save the planting, by reducing the ground saturation with detergent froth in the area, we have laid underdrains along the lee sides of our tanks (Figure 1). We also have tried 1/8-in. hardware cloth (fastened to the tank guardrails), which works fine on still days. However, I have measured froth 68 in. above the water level and if there is any wind at all it takes off over the screen. Rain breaks the bubbles, but most housewives want to do their washing—with detergents—when the weather is sunny!"

". . . confirmed our observations that higher concentrations of suspended solids in the aeration tank mixed liquor appeared to diminish the amounts of detergent froth. So, we are carrying about 3,000 p.p.m. suspended solids in the mixed liquor, with no detergent froth being noticeable. We have plenty of air, so the possible increase in air requirements can be very easily satisfied, if necessary."

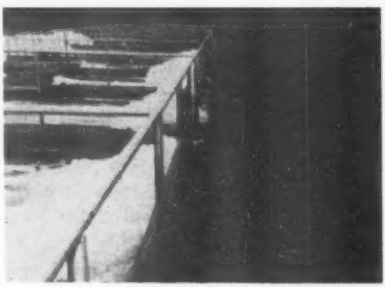

FIGURE 1.—Gravel-covered tile along lee edge of aeration tanks drains off foam spill condition that had been killing evergreen plantings.

Any other interesting experiences with aeration tank frothing—by detergents or otherwise? Send them along to "The Corner" and share them with other members of the "Bubble Brigade!"

Stainless Steel Stops Corrosion in Filter Screen

A Type 317 Armco stainless steel filter screen has been in use at the Baltimore, Md., sewage treatment plant over 12,000 hr. with no sign of corrosive damage. This service amounts to more than 17 months of continuous operation. Normal operating life of the bronze screen formerly used was 4,500 hr. maximum.

The stainless steel screen is 5 by 5 mesh made from 0.054-in. diameter wire woven to an 0.080-in. thick screen by the Cambridge Metal Cloth Company. It is fastened to the filter with 0.081-in. diameter Type 317 wire held in place with 18–8 stainless staples.

When the screen was last inspected it was found covered with a red rust, which was reported to have been deposited by the sludge filtrate. The deposit was easily removed with a dry cloth. Examination at 4-diameter magnification revealed a bright surface free of pits or crevice corrosion. According to the superintendent and the steel company representative, the screen was in excellent condition and should give more years of useful service. (Note: Type 317 stainless steel may not be used today for this purpose—by order of NPA.)

New Burette Unit

A new burette unit, featuring a polyethylene plastic reservoir requiring only a squeeze to fill an automatic self-leveling burette, has been announced by Hagan Corporation, Pittsburgh, Pa. Known as the "Squeez-O-Matic," it is said to be easy and simple to use, a time-saver, and requires only one hand, in contrast with older automatic burette assemblies, which required both hands for operation. A patent is pending for the device (Figure 2).

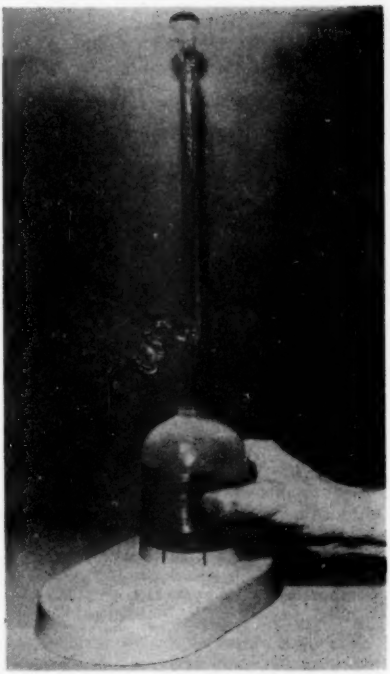

FIGURE 2.—New "Squeez-O-Matic" burette unit features plastic bottle.

Use of a plastic reservoir, a specially-machined polyethylene bottle, not only makes operation of the burette unit easier and simpler, but also provides a container that is highly resistant to chemical attack and will not contaminate standard titrating solutions. The unit is held in a special plastic base that provides a convenient and stable platform for the titration receptacle.

The new burette units are available in 25-ml. and 10-ml. sizes, graduated to 0.1 ml.

Reviews and Abstracts*

Kentucky Sewage Treatment Plants Reflect Progressive National Design Trends. By J. Stephen Watkins. *Civil Eng.*, 21, 7, 34 (July, 1951).

This condensation of a longer paper summarizes treatment practices. The tendency is to trickling filters, about one-third being high-rate, because of their ability to handle wastes with rapidly varying characteristics. In sludge digestion, external heat exchangers, closely spaced sampling outlets, and dead air space in the walls to provide insulation are common practice. Pre-aeration and chemical precipitation are emphasized for primary treatment units.

W. A. Hasfurther

Composting. *Surveyor*, 110, 443 (July 14, 1951).

This is a report of the discussions of a paper by the same name, which appeared in *The Surveyor* for June 16, 1951.

It was suggested that it might be possible to devise a semi-continuous mixing process at a combined sewage and refuse collecting station, using a concrete mixer. The method had not been tried, to the speaker's knowledge, and there might be reasons why it would not be satisfactory.

One discusser was concerned about the absence of brandling worms in the composting plants he had visited. It was recommended that after the thermophilic stage the compost should be turned out onto bare earth, surrounded by walls of some organic material, such as baled straw. If the worms did not appear of their own accord, they should be introduced.

In reply to questions asked in the discussion, the author stated that composting chambers are essential for the inclusion of sewage sludge in the compost. Paper is not a desirable component of the compost; it is preferable to collect it separately. No attempt can be made to control the quantities of trace elements in the compost, and it is known that excesses are toxic to plants. It may be argued that the trace elements in compost are probably in the right proportion, as they are contributed by the plants which had originally absorbed them. Compost had been found to contain all of the 21 elements necessary, with the exception of tungsten.

M. C. Rand

Agricultural Use of Sewage Sludge. By George E. Knight. *Surveyor*, 110, 460 (July 21, 1951).

In some rural areas, where provision exists for treatment of sewage sludge so that it can be offered to local farmers in dry form, sludge can be disposed of without cost. In other areas, however, farmers will not accept sludge. In such areas, straw-sludge composts may be more acceptable.

A proportion of one and one-half parts of sludge (dry basis) to one part of straw is satisfactory. Below this figure, the decomposition may not be sufficiently rapid, and the product may later immobilize soil nitrogen; above it, the sludge may tend to seal the compost heap and prevent access of air.

It is an advantage to place occasional lines of land tiles under the heaps to allow aeration. The lowest layer of straw is about 15 in. thick. Sludge is then spread over the straw, and the layers are thoroughly soaked with water. Further layers of straw and sludge are added, soaking each pair of layers after addition of the sludge, until a height of 6 ft. is reached.

It is probably better to allow at least six months' decomposition before using the composts in the field.

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill.

There seems to be no reason why considerable quantities of straw-sludge manure should not be made where conditions allow.

Such compost is deficient in potash, but this can be supplied in the form of fertilizer.

M. C. RAND

Cleaning of Porous Air Diffusers. *Surveyor*, **110**, 253 (Apr. 27, 1951).

This article is a report of the discussions of a paper by the same name which appeared in the Jan. 26 issue of *The Surveyor*. The authors, in introducing the paper, pointed out that the method was not really new, similar methods having been proposed by others as early as 1933. Their contribution was, therefore, to develop the details of a practical method for use on a large scale.

The fundamental problem is the prevention of plate clogging, the solution of which would make plate cleaning unnecessary. The use of formaldehyde gas seems to require large quantities for effective results.

It had been observed that high humidity caused increased back pressure. Setter had suggested that on rare occasions water may condense within the diffusers, causing such an increase. The authors of this paper believe that such occasions may be far from rare. When the air is compressed, then cooled by passing through the distribution system, condensation may occur, even when the original humidity of the uncompressed air is considerably below the dew point.

The first discusser pointed out that the total back pressure is affected by various interrelated factors, which seem to vary in importance from one works to another. He also stated that the total losses of tiles in cleaning by firing might run as high as 25 per cent, rather than the 8 to 10 per cent mentioned by the authors. It was questioned whether the forcing of solids into the diffusers when the air supply ceased was proven to be an important cause of clogging. It was noted that the authors' findings of long rinsing being needed to remove the caustic soda from the tiles were in good agreement with the theoretical time for its removal by simple diffusion.

Others brought out that although the authors stated that the chemical cleaning method almost completely restored the permeability of the plates, the effective life of the plates after cleaning is also of importance in evaluating the cleaning procedure. The difference in life of plates at various plants is due to a number of causes. For instance, it is to be expected that plates used in reaeration of sludge would clog more quickly than those used in complete activated sludge treatment.

M. C. RAND

Cleaning of Porous Air Diffusers. *Surveyor*, **110**, 267 (May 5, 1951).

In this continuation of the discussion of the paper by the same name which appeared in the Jan. 26 issue of *The Surveyor*, it was brought out that there are grave disadvantages in spasmodic or haphazard cleaning of diffusers. The air pressure required depends upon the worst section of the plant; occasionally, attention to a small part of the plant may considerably reduce the pressure required in the whole system.

Some doubt was expressed whether all the rust, oil, dirt, and particularly scale, inside the trays could be completely removed by chemical action alone.

At Birmingham, acid is used before alkali for cleaning of diffusers, the reverse of the procedure presented by the authors. Too much stress is placed on pressure at the compressor as an indication of blocking of plates. Dissolved oxygen in the tanks is a better guide.

In the experience of one of the discussers, injection of gas, gasoline, or chemicals into the air supply does not adequately clean the blocked pores of diffusers. Another said that oil carried over from the compressors should be added to the list of factors causing clogging.

In their reply to the discussion, the authors stated that acid treatment could not be recommended in cases where the acid would contact zinc. There was no evidence that the caustic soda weakened the tiles. Fired plates usually give good service up to one year after firing. After two years' use, chemically cleaned plates were giving uniform and satisfactory service.

M. C. RAND

Book Reviews

Handbook of Sewage Disposal (Taschenbuch der Stadtentwasserung). By Karl Imhoff. Fourteenth Edition. 308 pages, 86 figures. R. Oldenbourg, Munich, Germany (1951).

This renowned "pocket book," unique for its compactness, directness, and simplicity, is larger and better than ever in the new edition. As in the earlier editions, the arts of municipal drainage, wastes treatment, and water pollution analysis are reduced to elementary arithmetical terms through the ingenious use of charts and diagrams. Numerous examples are given to illustrate the calculations.

The book is thoroughly documented by 600 references to the German, American, and British literature. It affords, therefore, a remarkable cross-section of international practice.

Part I of the book includes three chapters on municipal drainage. Except for a new section on standards of materials and design practice in Chapter I, this part is relatively unchanged from recent editions.

Part II comprises five chapters dealing with the treatment and disposal of sewage and industrial wastes. New coverage is given here on aeration, sludge disposal, and on permissible stream loading with sewage effluents. The sections on activated sludge treatment and on industrial wastes have been completely rewritten and expanded. American experience is drawn upon heavily in the latter revisions.

The two chapters concerned with the admission of sewage effluents into streams and with self-purification of streams are especially well-handled for practical application. In fact, the entire book is noteworthy for its practicality, although (as the author cautions) it must be applied with sound judgment.

The English-written counterpart of the Taschenbuch is the book "Sewage Treatment," by Imhoff and Fair, John Wiley and Sons, Inc., New York and London (1940), which is closely related to Part II of the 8th edition of the German work.

Those who read German will find the Taschenbuch highly interesting and useful. It is more than an authoritative manual founded on Dr. Imhoff's long and diversified experience. The opportunity here to follow his deductive reasoning and common-sense logic is both fascinating and stimulating. W. H. Wisely

Data Book for Civil Engineers—Volume I, Design. Second Edition, 1951. 491 pp. Price, $10.00. **Volume II, Specifications and Costs.** Second Edition, 1951. 506 pp. Price, $13.00. John Wiley and Sons, Inc., New York, N. Y.

These completely revised second editions of the first two volumes of a three-volume series provide a concentrated collection of the type of data so necessary to day-to-day solution of the innumerable problems arising in civil engineering work. Laid out in easy-to-find and easy-to-read fashion, the two volumes are designed to provide the specialist with the basic information needed in dealing with activities associated with or bordering on his own field of work.

Volume I is laid out field by field to give the data necessary to design, place under contract, and construct all types of civil engineering structures. Modern codes, practices, and designs are emphasized. Sections on drainage, sewerage, sewage treatment, industrial wastes, and waste disposal present in capsule form most of the basic knowledge in these fields.

Volume II, also classified by major fields of civil engineering activity, provides data necessary to prepare specifications for the many types of work involved. Of considerable interest is the 80-page section on costs, including relative cost analyses for each type of work. A classified glossary of terms completes the data section of the book. Separate classified indexes for specifications, costs, and the glossary greatly improve the usability of the volume. H. P. Orland

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Proceedings of Member Associations

MISSOURI WATER AND SEWERAGE CONFERENCE

The 1951 Annual Meeting of the Missouri Water and Sewerage Conference was held at the Robidoux Hotel, St. Joseph, Mo., September 30–October 2, 1951, in conjunction with the Missouri Section, American Water Works Association. After a pre-convention discussion forum on September 30, the group saw a motion picture on "Flood Conditions," prepared by the St. Louis County Water Company during the flood of July, 1951.

Papers presented at joint meetings of the two groups on the mornings of October 1 and 2 included:

"Procurement of Materials," by R. J. Faust, executive assistant secretary, AWWA.

"The Keystone is the Foreman," by Stephen C. Casteel, assistant manager, East St. Louis and Interurban Water Co., East St. Louis, Ill.

"Protective Coatings for Metal Surfaces in Water and Sewage Plants," by H. J. Benjes, Black & Veatch, Kansas City, Mo.

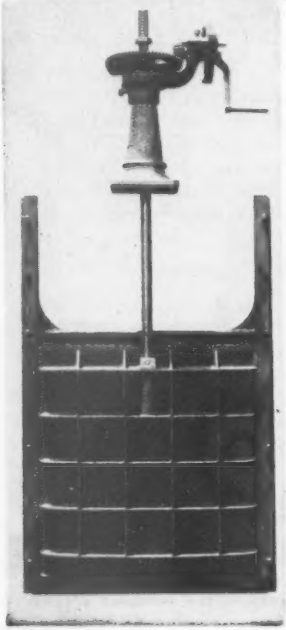
"A Practical and Possible Civil Defense Program for Water and Sewage Plants," by Ralph Hammond, director of Civil Defense, State of Missouri.

"The Effect of Atomic Warfare on Water and Sewage Plants," by C. P. Straub, U.S.P.H.S., Oak Ridge, Tenn.

"Floods and a Disaster Plan," by Melvin P. Hatcher, director, Water Department, Kansas City, Mo.

At the afternoon Sewage Section ses-

(*Continued on page 158a*)



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NUMBER TWO OF A SERIES

sion on October 1, the following papers were given:

"Basic Concepts of Stream Pollution," by C. R. Scott, Black & Veatch, Kansas City, Mo.

"Some Problems of B.O.D. Determination and Interpretation," by C. C. Ruchhoft, M. B. Ettinger, and W. A. Moore, U.S.P.H.S., Cincinnati, Ohio.

"High-Rate Oxidation Treatment of Sewage," by A. A. Kalinske and H. W. Gillard, Infilco, Tucson, Ariz.

The session closed with a demonstration of sewer cleaning by Alden Smith, Smith and Loveless, Kansas City, Mo.

At another separate Sewage Section session on the afternoon of October 2, the following papers were presented:

"Sewer Revenues," by W. G. Riddle, Burns and McDonnell Engineering Co., Kansas City, Mo.

"The Sedimentation Problem," by E. C. Cardwell, The Dorr Co., Chicago, Ill.

"Round Table of Operators' Problems," by a panel comprising S. C. Smith, superintendent of sewage works, Joplin; J. F. Schondelmeyer, city engineer, Sedalia; and M. J. Van Daventer, consulting engineer, St. Louis.

At the Annual Luncheon and Business Meeting, held on October 1, F. M. Veatch was nominated to receive the Federation's Arthur Sidney Bedell award.

Officers elected to serve during 1951–52 were:

Chairman: R. F. Bishop, Booneville.
Vice-Chairman: W. B. Schworm, Chesterfield.
FSIWA Director: L. J. Lukrofka, Springfield.
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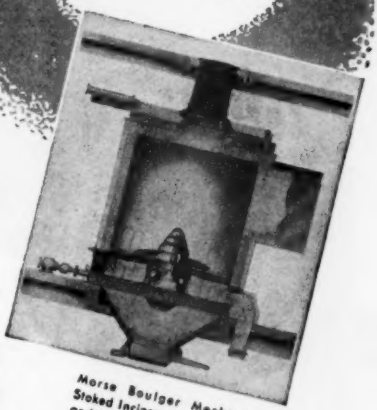

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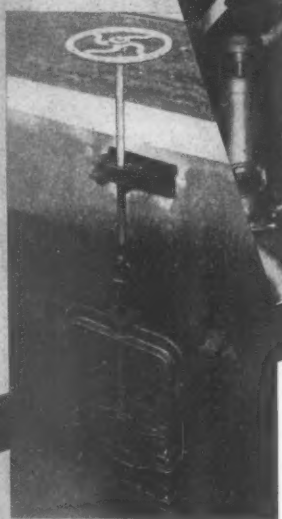

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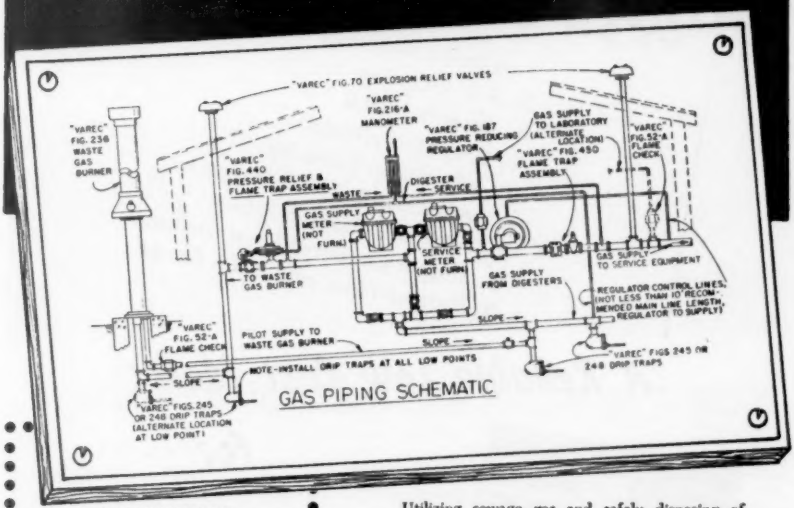
"VAREC" FIG. 70 EXPLOSION RELIEF VALVES
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. 216-A MANOMETER
"VAREC" FIG. 187 PRESSURE REDUCING REGULATOR
GAS SUPPLY TO LABORATORY (ALTERNATE LOCATION)
"VAREC" FIG. 52-A FLAME CHECK
"VAREC" FIG. 440 PRESSURE RELIEF & FLAME TRAP ASSEMBLY
"VAREC" FIG. 450 FLAME TRAP ASSEMBLY
WASTE
DIGESTER SERVICE
GAS SUPPLY METER (NOT FURN.)
SERVICE METER (NOT FURN.)
GAS SUPPLY TO SERVICE EQUIPMENT
TO WASTE GAS BURNER
GAS SUPPLY FROM DIGESTERS
REGULATOR CONTROL LINES (NOT LESS THAN 10' RECOMMENDED MAIN LINE LENGTH REGULATOR TO SUPPLY)
"VAREC" FIG. 52-A FLAME CHECK
PILOT SUPPLY TO WASTE GAS BURNER
SLOPE
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"VAREC" FIGS. 245 OR 248 DRIP TRAPS (ALTERNATE LOCATION AT LOW POINT)
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c. **FLAME CHECK**
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d. **EXPLOSION RELIEF VALVES**
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e. **WASTE GAS BURNER**
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f. **DRIP TRAPS**
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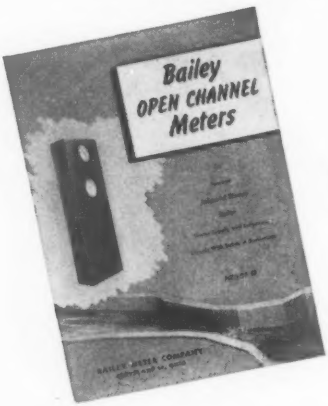

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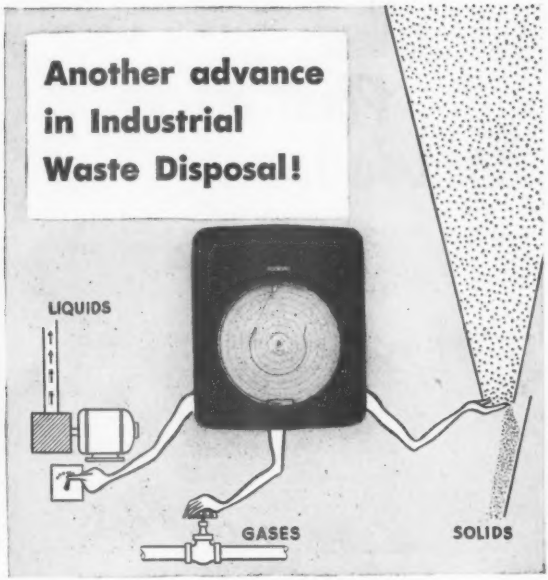

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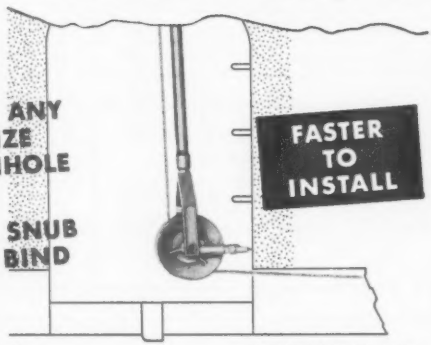

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